METALS & ALLOYS

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The Magazine of Metallurgical Engineering

INCLUDING

CURRENT METALLURGICAL ABSTRACTS

t Metal Mixer at Pittsburgh Crucible Steel Company

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The Magazine of Metallurgical Engineering

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CURRENT METALLURGICAL ABSTRACTS

EDITORIAL COMMENT

METALLURGICAL REFRACTORIES

THERE is a decided similarity between physical metallurgy and ceramics. The metallurgist deals with metals while the ceramist deals with metallic oxides. Both must depend on physical chemistry and equilibrium diagrams to give them their basic information. From that point of view, the ceramist is greatly handicapped because, unlike the metallurgist, he does not have relatively pure raw materials to deal with. Instead of 99.95% Cu, 99.5% Al, 99.99% Zn, etc., his commercial raw materials are "Georgia kaolin," "Austrian magnesite," feldspar, etc., which vary in composition according to the locality in which they occur, and generally contain highly undesirable impurities in quite large amount. Scarcely any raw ceramic material, save perhaps silica, approaches our average metallurgical raw materials in purity.

Instead of being printed as a separate department of METALS & ALLOYS, the information on U. S. and foreign PATENTS will shortly be merged into our Metallurgical Abstracts. We are now "tooling up" our editorial staff to bring about this change which will benefit our subscribers in two ways:

1. Abstracts of patents will be given. (Up to now this was not done.)

2. These patent abstracts will appear under our classified headings, instead of geographically, thus making it much more convenient for any subscriber and saving him the trouble of scanning many columns of small type.

Instead of smelting and refining his raw materials to the desired degree, and eliminating the harmful impurities as the metallurgist does, the ceramist takes whatever mineral products are available within a radius of favorable freight rates and blends them, retaining all the impurities of each, in the manufacture of ordinary fire clay, silica, magnesite and chrome refractories. He is in about the position the metallurgist would be in if the only alloys that could be made were those analogous to Monel metal, containing what the Lord put into the original ores. The style of the ceramist is therefore terribly cramped as long as he sticks to impure mixtures. Moreover, operating on the large scale he does, he may not economically be able to burn his product at as high a temperature as it may have to stand in service, so it may not attain the equilibrium corresponding to that temperature. The product is therefore not only relatively impure, but relatively raw as well. It is astonishing that under these handicaps fire clay brick are produced in various sections of the country from local raw materials, that serve as well as they do. On the other hand, it is not astonishing that refractories for exceedingly severe service are made by methods more closely approaching metallurgical practice.

It is a fortunate fact that many metallurgical processes requiring furnace operations are carried out at temperatures low enough so that the crude mixtures used as refractories are sufficiently refractory to deserve that name, and serve fairly well on the average. But the metallurgist is not entirely satisfied with the refractories he has to use, and the ceramist is seeking to produce better ones for metallurgical use, as is brought out by articles in this issue.

The special refractories that so far find use, such as silicon carbide, fused alumina, fused magnesia, fused mullite and the like, are mostly made partly by selection of raw materials and partly by high temperature chemical methods involving some refining. Were the problem of purification of the oxides less difficult and costly, it would be logical to extend this much further, use practically pure oxides and melt and "alloy" them together instead of merely mixing and sintering them. However, the attempts to purify the crude oxides by a reducing fusion reduce some of the heavy metal oxides, but leave those of the alkalies, and the fluxing action of sodium or potassium oxide is often far worse than that of the removable oxides.

It would appear that too little attention has been paid to the possible application of ore-dressing methods to the purification of ceramic raw materials, since a worthwhile beneficiation would often seem attainable by such methods. But it is unlikely that deposits of the various oxides needed of such nature as to be readily purified, will be found in many localities, so the use of mechanically purified "ores" could involve added cost for freight as well as the cost of beneficiation itself.

Hence, such improved refractories would have to command a higher price or at least find a more ready sale and thus command the market. It is being found a paying proposition to produce refractories so close to size that they will build into a furnace wall without using thick cement joints, since thin joints make for longer furnace life. In extremely severe service where the chemically-prepared super-refractories only will serve, prices have to be paid for bricks that at first strike the user, accustomed to paying fire-brick prices, as exhorbitant, and which tend to deter him from even trying out the super-refractories. Yet, when the real cost of refractories, in repairs and in idle time of smelting, melting and heat treating furnaces that are frequently down for repairs, is counted up, it often becomes plain that the super-refractories are economical in the long run.

It would appear that an intermediate product, not so expensive as the super-refractories, but one on which some extra expense of purifying the raw materials has been put, ought to find a place. The metallurgical engineer, perhaps more than most other users of refractories, is accustomed to reckon his costs on over-all performance and not to be too much deterred by an increase in first cost, if he is certain that the added first cost will be a paying investment. Hence, it would be logical to conclude that the metallurgical industries would be among the first to utilize such improved refractories, even at a higher price, once they were available.

But there are still too many metallurgical engineers

who watch some of the cost items pretty closely and are much concerned about coke consumption in the blast furnace or cupola, and fuel consumption in the open hearth or the annealing furnace, yet are not sufficiently "refractory-conscious" to pay much attention to their refractory problems, which may be of real importance in the balance sheet. Since refractories are important to the metallurgical engineers, several articles in this issue are devoted to the subject of metallurgical refractories, and other articles will follow in later issues.—

H. W. GILLETT

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CORROSION

COÖPERATIVE work on problems of common interest that are non-competitive in nature, has been recognized as the most economical method of attack but unfortunately such work often progresses all too slowly for lack of facilities and coördination. It is important of course in all such work to preserve and encourage individual initiative. Corrosion is a typical subject of the kind that readily lends itself to coöperative study.

To better promote the study of corrosion it is proposed to publish in one journal abstracts and a bibliography of all current literature on this subject. This plan has the approval of our various corrosion committees and this Journal has agreed to undertake the task of assembling all papers and reports with the aid, it is hoped, of these committees and similar organizations outside of our country.

The "Reichsausschuss für Metallschutz" (German National Commission for Metal Protection) has been recently reorganized on a permanent and broader basis under the management of a director, (Professor Dr. E. Maass) and a council for the study of all subjects connected with corrosion. Their most important undertaking has been the journal "Korrosion und Metallschutz" published under the auspices of this commission. In this journal German papers and abstracts of current contribution on this subject are regularly published. To further coöperate in the study of corrosion, several technical committees have been appointed dealing with this subject under the following headings:*

A. General Investigation and Research on Corrosion Processes and Their Influences.
Committee 1—"Theory of Corrosion"

B. Investigation of the Corrosion of Industrial Metals and Alloys.
Committee 2—"Iron Group" (iron, steel, nickel, cobalt, manganese, chromium)
Committee 3—"Non-ferrous Metals" (cadmium, zinc, copper, silver, tin, lead)
Committee 4—"Light Metals" (aluminum, beryllium, magnesium, Electron)

C. Metal Protection.
(*a*) Metallic Coatings
Committee 5—Coating with cadmium, zinc, chromium, nickel, cobalt, copper, brass, tin, lead.
(*b*) Non-metallic Coatings (paint, grease, lacquer, japan, etc.)
Committee 6—Paint, etc.
(*c*) Processes involving Oxidizing Melts, Pickling and Nitriding, etc., which produce a chemical change on the surface of the metal.
Committee 7—"Chemical Surface Treatment"

D. Cleaning and Preparation of Surface—Polishing and Spray Painting.
Committee 8—"Technical Surface Treatment"

E. Non-Metallic Structural Material.
Committee 9—"Wood"
Committee 10—"Stone and Cement"

F. Literature and Publication.
Committee 11—"History and Literature of Corrosion"
Committee 12—"Publication"

Special Committees

1. "Corrosion and Metal Protection in the Shipping Industry"
2. "Construction and Corrosion"
3. "Corrosion and Hygiene with Required Subjects"

The Reichsausschuss will exchange with the Editor of METALS & ALLOYS abstracts and contributions to the knowledge of corrosion and it is expected that similar arrangements will be made with organizations in other countries so that in each country, when this plan is in operation, the reader will find in one journal all the important contributions relating to this subject.—

F. N. SPELLER

*Private Communication from Dr. Maass

REFRACTORIES in Metallurgical Operations

BY CLYDE E. WILLIAMS*

METALLURGICAL industries are the principal users of refractories; in this country they consume approximately half of the total production. According to a study made in 1923,[1] open-hearth furnaces take over one-third of the refractory brick, blast furnaces and heating furnaces, nearly 7% each, cupolas and smelting furnaces, between 3 and 4% each, and malleable iron plants, over 2%. Since this survey was made, steel-plant capacity and the number of electric melting furnaces have been greatly increased.

Open-hearth furnaces not only use more refractories, but they present a greater variety of problems and more rigid requirements, and have been used for trials of more kinds of refractories than any other type of metallurgical furnace.

Basic Open-Hearth Furnace

Conditions in the basic open-hearth furnace are particularly severe on refractories, because of the high temperature, the corrosive basic slag, and the method of heating.[2] Open-hearth bottoms last 20 years, but must be patched after every heat. The hearth should be hard to withstand shock during charging, dense to prevent soaking up the slag, resistant to attack by slag, and thoroughly sintered to avoid formation of holes by parts of the bottom material coming loose. The customary practice has been to use clay brick on the bottom followed by magnesite or chrome brick and to fuse on this layers of a mixture of dead-burned magnesite with 10 to 25% of open-hearth slag.

The magnesite brick has been replaced at times by mixtures of dead-burned magnesite and portland cement. Crushed chromite has been used to replace the lower third of the magnesite-slag mixture, and some of the prepared dolomites (that is, calcined dolomite containing fluxes such as iron oxide, silica and alumina) have been tried in place of the magnesite-slag mixture. More refractory bottom materials (e. g., magnesia with less flux) cannot be used, as this would necessitate a sintering temperature higher than the silica roof would withstand. Domestic magnesite, to which iron oxide has been added to simulate Austrian magnesite in composition, has been used successfully. Some bottoms have been insulated. The holding capacity of one furnace was increased by the substitution of a few inches of insulation material for several courses of bottom brick.

Deep holes in the hearth are repaired with dead-burned magnesite or prepared dolomites, shallow holes with raw or calcined dolomite.

Roof and walls must withstand a high temperature (2800–3000° F.), the chemical attack of fume, chiefly iron oxide, the corrosive action of the furnace gases which contain solid particles, and rapid temperature changes. In addition, sprung roofs must withstand considerable pressure without softening or crushing. The oxide particles (chiefly Fe_3O_4) rising from the bath are absorbed in the open structure of the silica brick and gradually flux the silica particles away; the fusion

* Assistant Director, Battelle Memorial Institute, Columbus, Ohio.
[1] Where Refractory Bricks Go. *Iron Age*, Vol. 112, 1923, page 402.
[2] B. M. Larsen, F. W. Schroeder, E. N. Bauer & J. W. Campbell. Service Conditions of Refractories for Open-Hearth Steel Furnaces. *Carnegie Institute of Technology Coöperative Bulletin* No. 23, 1925.

Left Interior of Open-Hearth Furnace Prior to "Burning-In" the Bottom. (Courtesy of Wellman Engineering Company.)

Below Open-Hearth Floor at Great Lakes Steel Corp. (Courtesy Harbison-Walker Refractories Company.)

point of the hot face of the brick is so reduced that it gradually softens and drips into the bath. Although many kinds of refractories have been tried in roofs, none have yet been found to be as satisfactory or as cheap as well-made lime-bonded silica brick.

Ordinarily, roofs in basic open-hearth furnaces must be replaced after 100 to 125 days of continuous operation. This corresponds to 250 to 350 heats for large furnaces and 300 to 400 heats for small furnaces. Exceptions have occurred where, for example, 18-inch roofs in large furnaces last over 400 heats. The number of heats made during this time depends upon the size of furnace, the type or thickness of roof, and the number of hours required to make a heat. Until a few years ago, it was believed that thick roofs would last no longer than thin ones, that owing to the low heat conductivity of silica brick the inside would wear away rapidly until the flow of heat outward prevented overheating of the inner face. Recent work, however, has shown that heat flow is so rapid from the roof to the bath that thick roofs do not become overheated. Roofs of 15-inch thickness in the main section with 18 inches along skew-backs and 21-inch ribs have proved to be more economical than those of 12-inch thickness in the main section with 15 inches along the skew-backs and 18-inch ribs.

Pouring Pig Iron from Blast Furnace Ladle into Open-Hearth Charging Ladle at Great Lakes Steel Corp. (Courtesy Harbison-Walker Refractories Co.)

Charging an Open Hearth with Hot Metal at Great Lakes Steel Corp. (Courtesy Harbison-Walker Refractories Co.)

A 100-ton furnace with roof completely covered with 3 inches of insulation has been in operation for over 2 years. One campaign in this furnace lasted over 530 heats before the roof had to be replaced and the present roof already has gone over 600 heats. Such long roof lives of 240 to over 300 days prove the fallacy of the time-honored belief that silica roofs should not be insulated. The increased life cannot all be credited to insulation, because this furnace was equipped with a mechanical control of combustion that maintained a balanced draft over the hearth and prevented overheating periods with resultant longer refractory life. Other furnaces equipped with automatic control of combustion or with proper flame direction have given increased life of roofs. However, it is reasonable to expect that, if the heat loss through the roof is reduced, an equivalent heat transfer to the bath can be obtained with lower flame and roof temperatures.

The ease with which silica brick spall with sudden changes in temperature is another cause of failure. The spalling and dropping out of a brick from the roof exposes fresh surfaces of adjacent brick which spall or corrode quickly with the result that within a short time a large area of the roof must be replaced. The longer life obtainable with suspended roofs, which reduce spalling by avoiding the side thrust present in sprung arches, is not great enough, as yet, to justify their added cost.

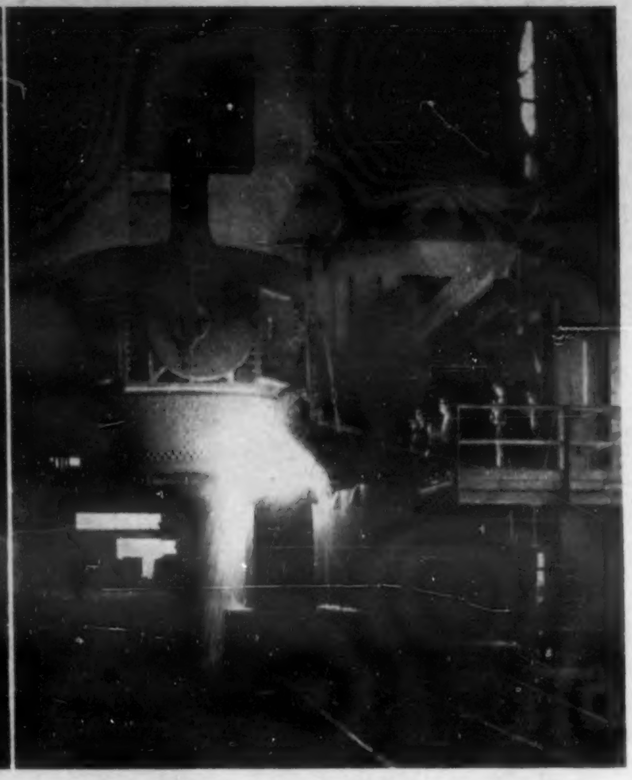
Front and back walls give about one-half the life of roofs. Deterioration, as with roofs, is caused by the absorption of iron oxide from the gas stream, the cutting action of the flame, and spalling which is especially severe in front walls near the doors. In addition, there is some chemical attack by slag splashed from the bath and by iron silicate that runs down from the roof. Silica brick are usually used, although many furnaces use magnesite brick, chrome brick, blocks of chromite ore, or "Metalkase" brick (grain magnesite encased in steel) especially in back walls.

When chrome or magnesite is used in back walls bottom-making material can be thrown upon the wall well above the slag line. Sloping back walls simplify this practice and are becoming more popular, although corrosion of this material from the siliceous slag formed above necessitates constant attention. Sloping basic back walls brought up to the skew-back and the use of magnesia or dolomite require the use of the more neutral chromite at the junction with the silica skew-back. Such sloping back walls in large furnaces last as long as 250 heats, but, owing to their low load-carrying qualities and spalling tendency, chrome or magnesite brick are not ideal for this use. Chrome-ore blocks resist spalling, but are not strong enough for use alone in the entire wall.

Ports and downtakes are usually built of silica. The upper port construction and the end walls or bulkheads opposite the port openings are in the direct path of the furnace gases, which, laden with oxide particles, have a more severe cutting action at this point than on the roof. Silica brick in the bulkheads wear out very rapidly, a life of 60 to 100 heats being usual practice.

Silica port bulkheads are sometimes faced with magnesite or chrome brick or with chrome ore. The bulkhead may be built of chrome or magnesite alone, sometimes with "Metalkase" brick which spalls less than the burned chrome or magnesite brick and has proved quite satisfactory in many installations. Unburned magnesite brick and magnesite brick of low iron content are giving excellent service. Such basic refractories are more resistant than silica to the chemical attack of the particles contained in the gas stream and give longer life. Life of bulkheads varies greatly, depending upon design of furnace and practice. From 150 to 400 heats have been obtained with these basic end walls.

Tapping an Open Hearth at Great Lakes Steel Corp. (Courtesy Harbison-Walker Refractories Co.)



Teeming Ingots at Great Lakes Steel Corp. (Courtesy Harbison-Walker Refractories Co.)

The life of silica ports is increased by covering with chrome or magnesite cement that presents a surface more resistant to attack by oxides contained in the furnace gases than silica does. High-alumina clay refractories have made some excellent records in water-cooled ports.

Mechanical control of combustion, improved design of furnace, and better control of the flame have increased the life of side and end walls and ports.

Checker Chambers

Checker chambers are designed to absorb from the exit gases and to give back to the air or gas for combustion as much heat as possible; it is desired at the same time to minimize the deposition of dust from the gas stream. The upper section, which is the hottest, usually reaches a maximum temperature of 2300° to 2400° F. The brick should not spall, should be dense for the greatest heat capacity, and should not fuse or react with the oxides contained in the exit gas. High-grade fire clay brick best answer these requirements and are generally used.

Air checkers gradually become clogged and must be cleaned out frequently as the clogging slows down the production rate which also affects the quality of some steel. One-third to one-half of the upper sections of the checker chambers are usually renewed when the roof is rebuilt and the deposit is removed from the lower sections. A large percentage of the removed fire clay brick is reclaimed.

The glazed surface that forms on clay checker brick does not affect heat absorption, but, because it is wet, when hot, probably does catch more dust than an unglazed surface would. The dust that deposits in checkers consists largely of Fe_3O_4.[3] This deposit in air checkers usually does not flux the brick and gradually accumulates until it must be removed; in gas checkers it fuses with and is absorbed by the brick as a result of more active FeO being formed by reduction of the Fe_3O_4 by thegas for combustion. For this reason, perhaps, the more refractory high-alumina fire clay brick and silica brick are not clogged so readily and are more easily cleaned than ordinary fire clay brick. Silica brick, however, spall badly and none of those removed are reclaimed.

The use of steel plates on outside walls of checker chambers to prevent air infiltration and of insulation to conserve heat have resulted in increased efficiencies and are being used extensively. The use of mechanical control of combustion has increased the life of checkers as it has that of the furnace.

Acid Open-Hearth Practice

Acid and basic open-hearth furnaces differ essentially only in hearth composition. Most acid open-hearth furnaces are small and are used for making steel for castings.

The bottoms are made of silica brick covered with sintered layers of silica sand. The silica (quartz sand or crushed gannister) must be as pure as possible. The silica hearth gradually absorbs iron oxide formed during the melting of the charge. The resultant bottom becomes a dense mass of silica bonded by iron and other silicates which gradually increase in amount, absorbing more silica until the refractoriness of the bottom is destroyed.

The slag, which is mainly iron silicate with some manganese and often calcium silicate, attacks the hearth at the slag line. In fact, a function of the bottom appears to consist in supplying silica for fluxing the iron oxide formed in melting the charge. Repairs are often made after each heat with silica sand or crushed gannister.

Destruction of the upper part of the furnace and clogging of checker chambers are caused by the same influences recorded under basic open-hearth furnaces.

Ladles for Steel

The lining for ladles used in teeming steel presents one of the most difficult problems in refractories. The lining should be dense to resist penetration and inert to chemical attack by silicates high in lime, iron oxide, or both. It should be hard to resist the cutting action of a stream of steel at 2800° F. and yet must not spall. Also, it must not adhere to the skull of metal and be pulled out when the skull is removed. A special type of fire clay brick used quite generally for ladle linings is not of high refractoriness and lasts only 12 heats. This is equivalent to the consumption of 2 brick per ton of steel in a 100-ton ladle. The life can be increased by using clay slurries to protect ladle linings, but the cleanliness of the steel is endangered. Monolithic linings of crushed gannister bonded with clay have given long life in some steel castings plants. High-alumina clay brick are reported to give double the life of the standard brick lining. Accuracy and uniformity of brick size are important in avoiding openings for penetration of slag. The use of several "rowlock" courses above the bottom and in the section nearest the metal stream has become rather general practice.

[3] B. M. Larsen, F. W. Schroeder, E. N. Bauer & J. W. Campbell. Service Conditions of Refractories for Open-Hearth Steel Furances. *Carnegie Institute of Technology Coöperative Bulletin* No. 23, 1925.

Clarence D. King. The Metallic Charge in Basic Open-Hearth Operations—Some Factors Affecting Operating Economies. *American Iron & Steel Institute, Preprint* Oct. 1931 Meeting.

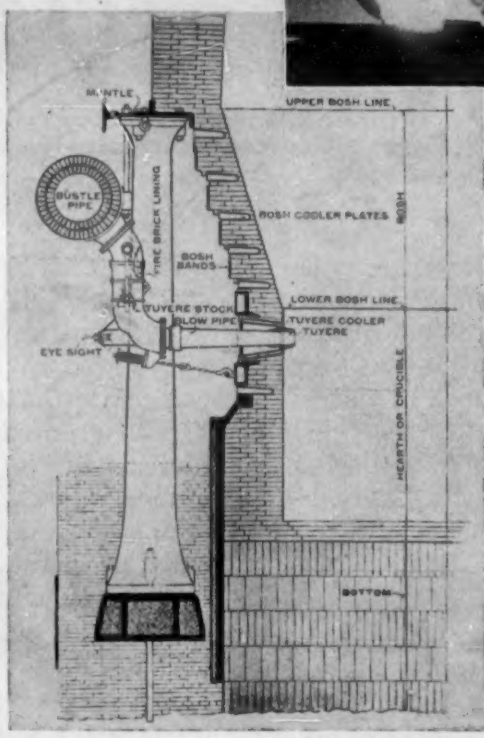
Iron Blast Furnace

Although a single iron blast furnace lining lasts for several years of continuous operation, so many brick are required that the blast furnace ranks high in the consumption of refractories. One-quarter to over three-quarters of a million brick (in 9-inch equivalents) are used in lining a present-day furnace, depending upon its size. On the average, 1 to 2 brick are consumed for each ton of iron made. Some furnaces show a much lower and some a higher consumption, the lining life varying with the kind of iron made, the character of the charge, and the quality of stock distribution. Furnace linings have shorter life when making ferro-alloys than when iron is the product.

Tapping the Blast Furnace. (Courtesy Colorado Fuel & Iron Company.)

The three zones of the lining, the hearth and bosh, the shaft or inwall, and the top, are subjected to different conditions and therefore have different refractory requirements. The hearth receives molten iron and slag at a temperature of 2500° to 2800° F. and at the time of casting holds from 100 to 250 tons of molten material. This weight of fluid plus the blast pressure puts the refractory under severe pressure, especially on the bottom.

The temperature in the tuyere zone is 2900–3100° F. but considerably lower at the surface of the inwall. The slag is essentially calcium aluminum silicate. The principal requirements of hearth and bosh brick are resistance to deformation under high loads at high temperatures and resistance to chemical attack by the slag. They must also be dense to prevent penetration of the molten metal and slag, and hard to avoid too much abrasion by the charge, particularly in the bosh.



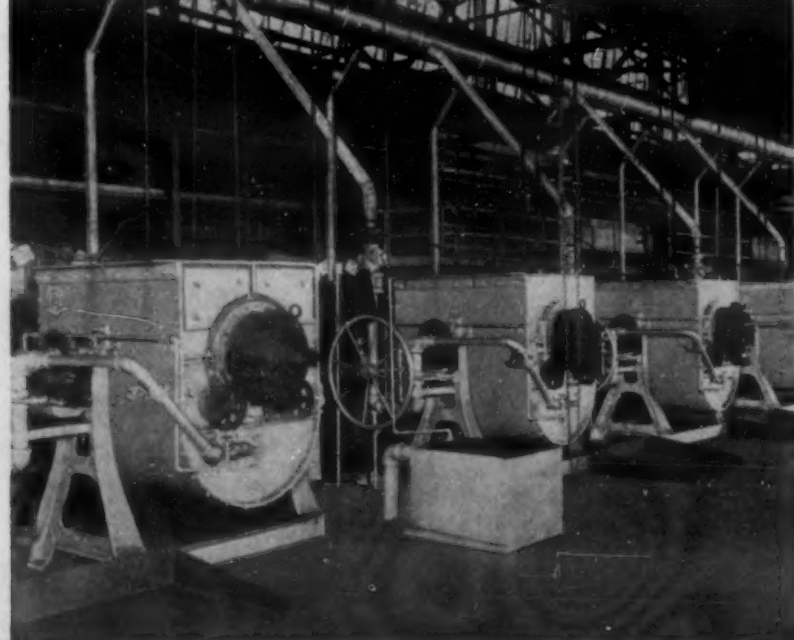
Sectional View of Blast-Furnace Hearth and Bosh. (Courtesy of Harbison-Walker Refractories Company.)

The inwall of the shaft should be hard to resist abrasion by the charge and dense to prevent penetration by the gas. The top brick is heated only to about 400° F. but must resist the shock and abrasion of the charge.

For lining the hearth and bosh, fire clay brick are used that have a high content of flint clay to give high fusion point and high resistance to load at elevated temperature. Water-cooled iron plates inserted in the wall maintain the brick at temperatures low enough that they remain rigid at the high pressure and withstand the corrosive action of the slag. Hearth bottoms are built several feet thick, but, owing to the high temperature and pressure, the brick soften and are gradually replaced by metal which freezes, forming a "salamander."

Inwall brick need not be so refractory as bosh brick and, hence, contain less flint clay. Cooling plates are used part way up the stack above the mantel, but their value in maintaining furnace lines is questionable. The brick should be hard to prevent abrasion and dense to prevent disintegration. Penetration of furnace gas into the clay brick causes it to disintegrate by the reduction of iron oxide in the clay either to metallic or ferrous iron which then catalyzes the decomposition of carbon monoxide into carbon and carbon dioxide.[4] The maximum amount of deposition was found at about 840° F. Burning inwall brick to a higher temperature to convert iron oxide into a less easily reducible form diminishes the amount of disintegration but may cause spalling in the upper part of the stack. Selection or cleaning of clay to insure the absence of iron in a harmful form is the best remedy.

Zinc contained in the charge causes swelling and disintegration of the lining. Menke[5] reports that furnace shells are cracked by this action and gives analyses of brick taken from several furnaces. Zinc, both as



Battery of Carburizing Furnaces. (Courtesy W. S. Rockwell Co.)

[4] C. E. Nesbitt & M. L. Bell. The Disintegration of Fire Brick Linings in Iron Blast Furnaces. *Yearbook American Iron & Steel Institute*, 1923, pages 216–242.

B. M. O'Hara & W. J. Darby. The Disintegration of Refractory Brick by Carbon Monoxide. *Journal American Ceramic Society*, Vol. 6, 1923, pages 904–914.

[5] P. O. Menke. Lining Failures Caused by Zinc. *Iron Trade Review*, Vol. 70, 1922, pages 1409–1410.

Charging an Ingot into the Soaking Pit. (Courtesy Colorado Fuel & Iron Company.)

metal and oxide, was often found with carbon several inches from the inside surface. From there nearly to the shell the lining was disintegrated. More metallic zinc was found near the shell, especially where water-cooled. A plausible explanation of this phenomenon is that zinc vapor, formed in the lower part of the stack at about 1800° F., with the furnace gas, penetrates the lining until the temperature drops to the point at which zinc condenses. At this lower temperature the gas is oxidizing[6] to zinc and zinc oxide is formed.

Oxides of sodium and potassium vaporized in the lower part of the furnace condense on the cooler wall above and decrease the life of the lining. As much as 25% of these oxides is reported[7] to have been found in brick taken from a furnace. These oxides are active fluxes of clay refractories. No economical change in refractory composition is apparently possible, though a denser brick should diminish penetration of these fluxes.

Heating Furnaces

The term heating furnaces includes soaking pits, billet and bar reheating furnaces, annealing and normalizing ovens, forges. Although in the aggregate such furnaces represent one of the largest consumers of refractories, so many different types of furnaces and operating conditions are involved that space will not permit a discussion of these uses. In most types of heating furnace, temperatures are relatively low; the main requirement is resistance to spalling caused by sudden temperature changes that result from an intermittent operation or the admission to a hot furnace of large pieces of cold metal.

In such cases high-quality fire clay brick are suitable. In soaking pits and some reheating furnaces, iron oxide is formed and may attack the bottoms and lower side walls. Magnesite is more refractory [to this slagging action, but more subject to spalling than fire clay. Unburned magnesite used in bottoms and lower side walls has shown more resistance to spalling than the more common burned magnesite brick.

[6] C. G. Maier. Zinc Smelting from a Chemical and Thermodynamic Viewpoint. *Bulletin* No. 324, *U. S. Bureau of Mines*, 1930.

[7] M. C. Booze. Refractories for Blast Furnaces and Coke Ovens. *Blast Furnace & Steel Plant*, Feb. 1926, pages 86–88.

Reverberatory Copper Smelting Furnaces

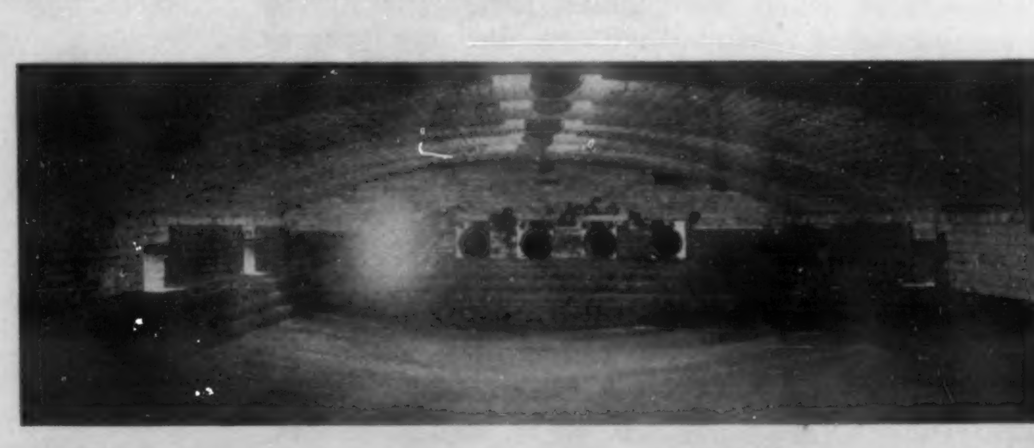
Reverberatory furnaces for smelting copper ores are somewhat similar in design and operation to open hearth steel furnaces, but they are longer and narrower and heat is applied at one end only. Oil, pulverized coal, or gas is used as fuel. The operation is largely one of melting in the hot end of the furnace a mixture of partly-roasted fine ores, consisting mainly of copper and iron sulphides and gangue, to form a copper-iron sulphide matte and a slag. The fused mass then flows to the tapping end of the furnace where the slag and matte, now separated into layers, are tapped out. The slag is essentially iron silicate, containing about 40% each of FeO and SiO_2 and some lime and alumina.

The capacity of a given furnace depends upon the rate of heating and hence the flame temperature, which in turn is limited by the safe-operating temperature of the furnace refractories. Furnace capacities have been trebled in the past 20 years without increasing furnace dimensions, except the height in some cases. Shorter, sharper flames have replaced the long, lazy flame characteristic of older practice. Furnace temperatures vary from 2600° to 2800° F. with flame temperatures perhaps 150° higher at the firing end. Furnace temperatures remain fairly uniform as the process is continuous. Owing to the fine state of division, the charge dusts badly.

Bottoms must be dense and strong to prevent loss by percolation of the matte and to remain in place under the heavy load of matte and slag. Silica sand sintered in place by a long firing period is the most common form of hearth. It is then heated with successive thin charges of either crushed slag or calcined ore, which is absorbed to form a bonded bottom. The bottom gradually becomes completely impregnated with matte and slag which ultimately produce a hard, dense hearth and the sand finally becomes almost entirely replaced. Silica brick and magnesite brick bottoms also are used.

Side walls, unless protected, are subject to attack by the iron silicate slag which at the high temperature is strongly corrosive to both acid and basic refractories. Until a few years ago, silica side walls were used almost exclusively. Charges were fed in at the center near the firing end of the furnace. Side walls wore away rapidly and furnaces were shut down periodically for patching. In 1909 side charging of siliceous ore through doors in the roof was adopted.[8] This practice not only protected walls from deterioration, but added life to the silica roofs which spalled badly after each shut-

[8] H. O. Hofman & Carle R. Hayward. Metallurgy of Copper. McGraw-Hill Book Co., New York, 1924.



Reverberatory Furnace used at the Calumet & Hecla Smelting Works, Hubbell, Michigan.

down. This practice was later displaced by adding all the charge at the side.

Side charging and the use of silica walls became general practice and have remained so, except that as a result of the famous Carson patent suit[9] some smelters reverted to center charging and tried magnesite and chrome side walls, water cooling of silica walls, etc. When the charge consists entirely of fine material of low angle of repose, side charging does not fully protect the side walls. As it is difficult, in such cases, to pile up the ore along the walls, wall life is low and center charging may as well be used. For such practice, there is need for better side wall refractories to resist the extreme conditions, particularly spalling and the corrosion of the hot ferrous silicate slag. The newer products, unburned magnesite brick and burned magnesite brick of low iron content, are being used with success.

In the reverberatory as in the open-hearth furnace, silica brick have proved to be the cheapest and most satisfactory roof material. Also in both types of furnace the main cause of failure of the roof brick is the same, i. e., the lowering of the fusion point by the absorption of fluxes. Oldright and Schroeder[10] showed that in the reverberatory copper melting furnace the dust from the charge, consisting mainly of copper sulphide and iron sulphide, penetrates the roof brick, forming the oxides of copper and iron and causing the silica at the surface of the brick to melt down at temperatures several hundred degrees below the fusion point of the brick. Samples of roof "drips," tested by these investigators, had fusion points of 2370° to 2600° F. and contained 7 to 15% iron oxide and 1 to 12% copper oxide.

In spite of this severe action and the excessive rate of driving furnaces are now given, some exceptionally long roof lives have been reported. A survey by the A. S. T. M.[11] indicated that the average life of arches in the hottest part of the furnace was between 3 and 6 months. Much longer records have been reported, ranging from one to over two years, but the longer ones usually were made when the ore charge was comparatively coarse.

To lessen the severe corrosion and spalling in the area around the side-charging holes, magnesite brick have been tried. Such good results have been obtained with the unburned brick and with the burned brick of low iron content that larger sections of roof have been made of these products with excellent results.

Copper Refining Furnaces

Copper refining furnaces are similar in design to reverberatory smelting furnaces and burn pulverized coal, oil or gas. The charge may be solid or liquid (converter) copper. The operation is intermittent, i. e., charges are melted, refined and cast. The furnace operating temperature is 2800° F. In large furnaces, casting requires several hours and the furnace cools down considerably.

Bottoms must be dense to prevent penetration of metal and strong enough to support the heavy charge of metal. They are usually made of silica sand, sintered, and bonded by the method used for smelting furnace bottoms, except that copper is used instead of slag or matte. The copper that penetrates the pores between the grains of silica becomes oxidized and forms a strong bond of copper silicate. The average life of such bottoms is reported[12] as two years. Silica brick have replaced silica sand in several installations and magnesite bottoms have been tried. Usually, bottoms are air-cooled from below to avoid the possibility of a breakout caused by the bottom becoming too hot.

Side walls and roof are corroded by copper oxide which forms a slag on the metal bath and which is formed when copper splashes on the walls and roof and is oxidized. Also, copper oxide fume forms during the oxidizing period and, rising from the bath, is absorbed into the refractory. In some cases sodium carbonate is added to the bath as a flux for certain impurities. The resultant slag is extremely corrosive to the usual refractories. Resistance to spalling is required, as in many furnaces changes in temperature are large and rapid. The larger furnaces require high load resistance in roof refractories.

Until recent years side walls were made entirely of silica brick. Most furnaces now use magnesite brick on the inside of the wall from the bottom to above the slag line, with either silica or fire clay brick above the slag line, and some build entire side walls of magnesite. As the refining slags are basic, it is logical to use a basic refractory in contact with them. Magnesite-lined lower side walls last about one year. Upper side walls of silica are burned out by the penetration of copper oxide which greatly reduces the fusion temperature of silica and they must be repaired frequently. Roofs are made of silica brick and are subject to corrosion by copper oxide, as explained above. Spalling of silica roof and side wall brick causes cracking and disintegration. Roofs in a typical furnace must be repaired every 2 months and replaced about every 6 months.

Sections of roof nearest the skew-backs made of magnesite brick, either unburned or of low iron content, have given increased life or lower cost. Some furnaces are now built with the entire sprung roof made of these newer types of magnesite brick.

Iron Cupola

Although but few refractory brick or blocks are used in a cupola lining, the daily replacement of brick in the melting zone brings the total consumption to a high figure. From 1 to 5 brick, in 9-inch equivalents, are used per ton of iron melted, depending upon the output and practice. Refractory requirements for the cupola are similar to but more severe than those for the blast furnace.

The temperature at the melting zone is 2800–3000° F. Lime added to the charge to flux the coke ash forms a corrosive calcium aluminum silicate slag which contains 7 to 10% iron oxide. Pieces of descending coke abrade the lining which at the melting zone is already soft. These requirements might be met quite satisfactorily but for the added requirement of resistance to spalling. In ordinary practice, only about one hour is taken to heat the cupola before turning on the blast to melt the first charge. This quick heating to the melting temperature, although severe, is not nearly so destructive as the common practice of cooling the lining at the conclusion of the melting period by dropping the bottom and spraying with water.

A good grade of fire clay brick is used most extensively for patching as well as for the original construction. A more dense, hard-burned fire clay brick might resist abrasion and slag attack, but would fail by spalling. More refractory, high alumina fire clay brick

[9] Carle R. Hayward. The Mineral Industry During 1929, Vol. 38, 1930, pages 179–180. McGraw-Hill Book Co., New York.

[10] G. L. Oldright & F. W. Schroeder. Suggested Improvements for Smelting Copper in the Reverberatory Furnace. *Transactions American Institute Mining & Metallurgical Engineers*, Vol. 76, 1928, pages 442–464.

[11] Industrial Survey of Conditions Surrounding Refractory Service in the Copper Industry. *Proceedings American Society for Testing Materials*, Vol. 26, 1926, pages 253–263.

[12] Industrial Survey of Conditions Surrounding Refractory Service in the Copper Industry. *Proceedings American Society for Testing Materials*, Vol. 26, 1926, pages 253–263.

apparently last no longer than a good grade of fire clay brick. Extremely refractory, high priced brick have not lasted long enough to warrant their extra cost, and it is doubtful if much progress will be made in increasing the life of cupola refractories until operating conditions in the foundry are adjusted to favor the cupola lining. Foundrymen, as a rule, are prone to accept present conditions, because the cupola bottom must be prepared before each melting cycle, so the added labor and time required for patching is not considered an important item. Some foundries have obtained better results with silica brick which, of course, spall badly, others with sandstone blocks of high purity which do not spall badly but are softer than fire clay or silica brick. Many other kinds of material have been tried.

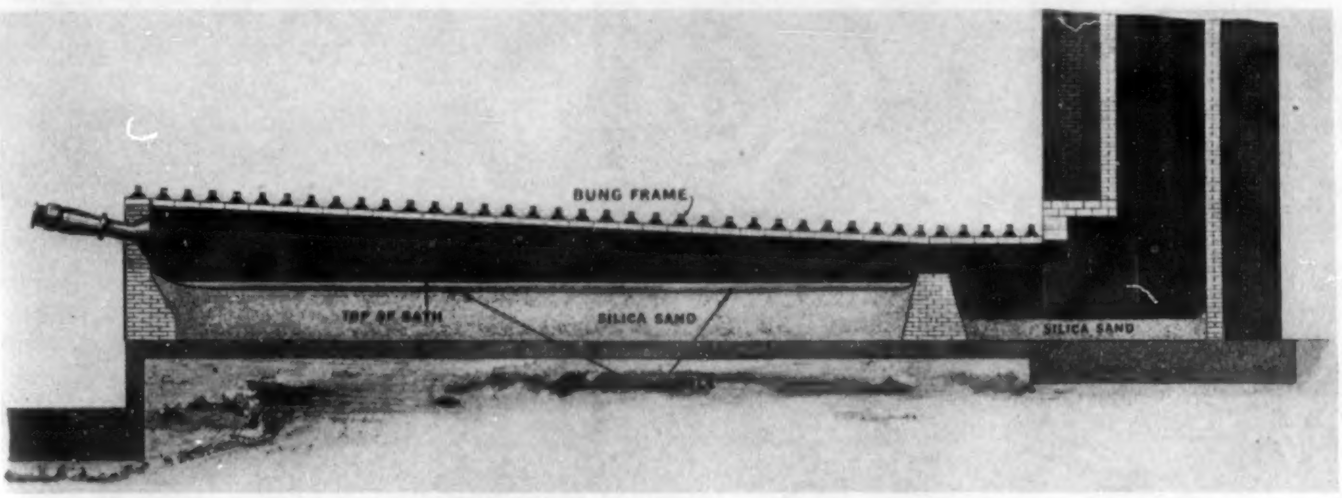
Patching of small holes and daubing or completely covering the surface of the lining in the melting zone is practiced before every melting campaign. A mixture of silica, crushed fire brick, and plastic fire clay is used. Without such maintenance, replacement of lining would be more frequent. The lining above the melting zone is subjected to slag attack, spalling and abrasion, but with reasonable care, it will have a long life. The upper portion must withstand the shock of heavy pieces of metal thrown against it and wear of the refractory just below the charging door is severe. Cast iron blocks have proved very satisfactory substitutes for refractory shapes in this area.

Nearly every cupola man has his pet refractory and patching method and little appreciation of the cost and grief that could be saved by the correct use of a refractory material of suitable properties.

Air Furnace for Malleable Iron

The air furnace used for melting malleable iron is a long and narrow reverberatory type, fired at one end usually with either lump or pulverized coal, and occasionally with oil. The average capacity is 20 tons. The roof, supported on the side walls, is made up of a series of arches, called bungs, so held in iron frames as to be removable for making repairs or admitting the charge. Two bridge walls hold the metal on the hearth.

The metal is heated to 2700° to 3100° F., depending upon the type of castings to be made. Flame temperatures must therefore be 2800° to 3200° F. Cold pig iron and scrap are charged through openings made by removing the central or charging bungs. An iron silicate slag is formed by corrosion of the bottom material, walls and roof and from the oxidation of the iron. An excellent study of malleable furnace refractories has been made by the Joint Committee on Foundry Refractories sponsored by the American Foundrymen's Association and the American Ceramic Society.[13]



View of Pulverized-Coal Malleable Iron Furnace.

(Courtesy of Harbison-Walker Refractories Company.)

The hearth bottoms are made by tamping silica sand, crushed fire clay brick, or a mixture of these onto the fire brick bottom. It is gradually corroded by the slag and damaged by charging or during skimming. Average bottom life is 12 to 17 heats.[13]

Side walls fail largely through corrosion by the slag and the solid particles in the furnace gases, and through abrasion of the charge. Parts near the charging bungs are subject to spalling when bungs are removed for charging; improper charging causes severe abrasion. First grade fire clay brick are used, and side walls are frequently patched with new brick and daubed with fire clay. Medium burning of these brick is recommended by the Joint Committee referred to above. The average life of side walls for 20-ton furnaces is 20 to 25 heats.

Roof brick fail as a result of both the physical and chemical action of the solid particles contained in the gas stream, by spalling, and sometimes by actual fusion. The pressure on the brick is not high, so a high fusion point is more important than high load resistance. Schurecht and Douda[14] found that fire bricks that deform as much as 6.35% in the load test may be very serviceable as bung brick and that brick that pass very high load and softening tests often fail in service. First quality fire brick are used in bungs. The average life as reported by the Joint Committee for 15 to 20 ton furnaces is 23 heats for charging bungs and 45 heats for fire box bungs with hand firing, and 14 heats for charging bungs and 22 for fire box bungs, with pulverized coal firing. The lower life for pulverized coal is probably due to the corrosion by coal ash.

Direct Arc Electric Furnace

The direct arc furnace is used for melting cast and malleable iron, steel and alloys of high melting point. Acid lined furnaces are used for iron, both acid and basic for steel, and usually basic for high alloy steels and alloys. The close proximity of the electric arc to the walls requires careful operation and correct design to avoid rapid destruction of the furnace lining. As a result of advances made by some furnace manufacturers in improved design and in the instruction of operators, a comparatively long life of lining can now be obtained with commercial low-priced refractories.

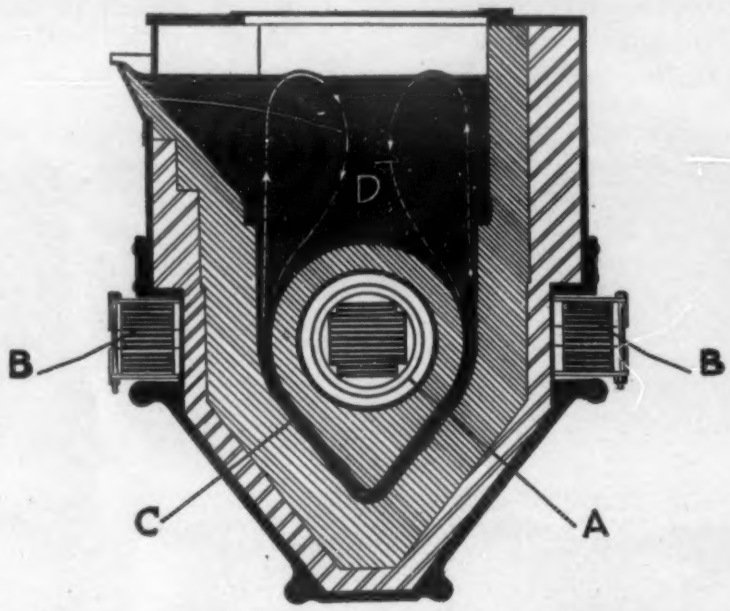
Acid Lined Furnace. Bottoms of acid lined furnaces are built and patched similarly to those of open-hearth furnaces. Silica sand or crushed gannister often mixed

[13] Preliminary Report of the Subcommittee on the Survey of Conditions in the Malleable Industry. *Transactions American Foundrymen's Association*, 1926, pages 88–117.

[14] H. G. Schurecht & H. W. Douda. The Behavior of Fire Brick in Malleable-Iron Furnace Bungs. *Journal American Ceramic Society*, Vol. 6, 1923, pages 1232–1241.

with a little fire clay, is tamped into place, dried and sintered by arcing the electrodes on pieces of electrodes resting on the bottom. In steel melting practice, iron oxide is gradually absorbed into the bottom and forms a bond of iron silicate. Bottoms are patched with silica after every heat. Because of its relatively small size, careful attention can be given to the maintenance of an electric furnace bottom, and when melting steel long bottom life can be obtained. When melting iron, however, as long life is not obtained in spite of the generally lower operating temperature. W. E. Moore[15] has advanced the plausible explanation of this phenomenon, that because of the strongly reducing condition of the bath, owing to the presence of much carbon and silicon, the iron silicate bond is destroyed or prevented from forming.

Walls and roof are built of silica brick. They are subjected to the heat of the arc and to corrosion by iron oxide particles rising from the bath. The common practice of cooling down over Sundays and forced long shut-downs cause spalling. Many furnaces that operate intermittently with long shutdown periods make roofs of fire clay brick. Although fire clay brick do not possess the equivalent resistance of silica brick to high temperatures and to chemical corrosion their resistance to spalling justifies their use in such practice.



Sectional View of Vertical-Ring Induction Furnace. A—Primary Coal. B—Transformer Iron. C—Secondary Melting Channel. D—Metal Bath. (Courtesy of Ajax Electric Furnace Corporation.)

The average life of roof brick in a 3-ton acid-lined furnace, making steel for castings, is 200 to 300 heats; as high as 1000 heats have been obtained. Walls last about twice as long as roofs. The average life of roof and wall brick is longer for iron than for steel melting practice. Some iron, however, is now being poured at as high temperatures as steel, i. e., 2800–3000° F. Consequently lining life is lower than usual.

Basic Lined Furnace. The hearth in the basic lined electric furnace is made by tamping and sintering in on top of magnesite brick, dead-burned magnesite mixed with slag for bonding. By sintering thin layers at a time with the electric arc playing upon broken pieces of electrodes, the bottom can be made dense and hard throughout. Refining slags, although strongly basic, contain sufficient silica to be corrosive and the hearth must be patched after each heat; raw and sintered dolomite are used for small patches, grain magnesite for large ones. Lower walls usually are made of magnesite brick. The newer magnesite brick of low iron content have been used for walls up to the skew-back and are said to possess good resistance to spalling and swelling.

Upper walls and roofs are made of silica brick. Corrosion of these is more severe in basic than in acid practice, as lime as well as iron oxide particles permeate and attack the brick. Likewise, higher temperatures are frequently used in the refining operations. The average life of refractories in roofs and walls of basic furnaces is about half that of acid furnaces, i. e., for one of 3-ton capacity the roof life is 100 to 150 heats and wall life about 300 heats.

Indirect Arc Electric Furnace

Although this article chiefly deals with furnaces that annually use a large quantity of refractories, some of the smaller electric furnace operations are included because they present unusual requirements and have made much progress in the adoption of some of the newer refractories. Among these is the indirect arc, rocking type furnace. Originally designed for melting brass and bronze, this furnace now is being used also for melting iron and steel.

Copper alloys that contain 50% or more copper, and zinc, tin or lead are poured at 1800° to 2400° F. After the charge in the furnace is melted, rocking begins and the entire lining, except the end walls and the portion near the door, is continually washed with metal and thus kept at about the temperature of the metal. A tight, dense lining that remains rigid at the melting temperature is the primary requisite. Molten lead or zinc will penetrate into pores or fissures, causing cracks on cooling and increasing the thermal conductivity. The lining must withstand the mechanical and thermal shock of charging cold metal to the hot furnace. Damage frequently results from over-heating of the end, due to operating with the arc off center. High resistance to spalling is essential, owing to the intermittent type of operation in many plants.

The inside lining consists of brick or preformed blocks of high alumina fire clay, backed up with less refractory material of lower heat conductivity. Some have monolithic linings of the mullite type refractories. Patching is done, sometimes daily, sometimes only weekly. The life of the lining depends, of course, upon the care exercised by the operator and also very largely upon the frequency of patching. Careful, daily patching results in an exceptionally long life of lining.

The average lining life varies from 1000 to 3000 or more heats on a one-ton furnace, depending upon the melting point of the alloy being made and the amount of patching done. Some operators prefer to reline after a relatively short life when the heat loss through the lining begins to mount up, and others believe frequent patching with consequently longer lining life to be more expensive in the end than less attention to patching and a shorter life.

With the advent of high-test cast iron and duplexing of cupola metal, the rocking indirect arc furnace has been adapted to cast iron practice. Also, some plants are melting high alloy steels in this furnace. The high temperature (2800–3000° F.) required for such service is being met by the use of monolithic mullite type refractories. Other special refractories are being tried. Preformed block linings and monolithic linings used up to about a year ago gave poor service. The monolithic lining now used is made of such a mixture of sizes as to give a strong, dense mass and is heated with the

[15] Personal Communication.

furnace empty at a temperature approaching its fusing point until vitrification has taken place throughout its depth. Lining life of from 300 to 500 heats have been reported for these linings on cold metal charges and several times this number on duplexed heats. Initial tests have indicated a possible long life of linings made with dense blocks cast from the melted mullite.

Induction Electric Furnaces

The vertical-ring or high-frequency induction furnace used for melting brass presents some unusual refractory requirements. In this furnace, heat is generated by the resistance offered by a wide, but thin, V-shaped loop of metal in a ring to induced current from a primary winding. The molten metal acts as the secondary winding of a transformer whose primary winding and core are within the secondary loop. Metal in the reservoir above feeds down into the ring where metal is circulated by the force of the electric flux.

The lining between the metal and the primary coils must be thin for high electrical efficiency. The main cause of failure is penetration of metal into cracks, causing short circuiting or diffusion of metal into the lining to lower the electrical efficiency. Alloys of over 3% lead content and those of high melting points, with pouring temperatures of 2500° F. or above, are particularly damaging in this respect. For rapid melting, the metal temperature in the V section should be 400° to 500° F. above the pouring temperature.[16] High zinc brasses cause a gradual building up of zinc oxide in the loop and furnaces that have run for a long time become choked up.[17] Inasmuch as molten metal must always be kept in the loop, and because of the peculiar construction, the lining in the loop cannot be repaired. Alloys of high melting point cause some wear on the refractory, but the motion of the metal is not rapid enough to cause much abrasion. Low thermal conductivity of the lining is desirable.

A rammed-in mixture of asbestos cement and fire clay gives satisfactory service for alloys of low lead content and especially for yellow brass. St. John[16] states that the usual lining life varies from 700 to 1500 heats, and Adam[18] reports that 8 to 10 million pounds of yellow brass have been melted without relining. It is not so satisfactory for alloys of higher melting point, owing to either softening, or the penetration of metal into the lining adjacent to the primary coil, causing high power losses.

For alloys that require pouring temperatures of 2500° F., or above, a completely satisfactory lining has not yet been developed. Such alloys are being melted commercially and much experimental work has been done. Preformed refractory clay linings have been tried, but these are either too thick or too porous. Rammed linings of electrically sintered magnesia bonded with sodium silicate are used in this country for melting high-copper alloys, nickel brass, and pure copper. The life is one-tenth to one-fourth that of the asbestos-fireclay lining on yellow brass. In England also the rammed lining is used. It is made by tamping the dry refractory cement around a metal template inside the furnace and sintering it in place by means of the induced current. A single lining gives from 50 to 250 heats when melting nickel and its alloys[19] and 600 heats when melting copper.[20]

[16] H. M. St. John. Refractories for Brass Foundry Furnaces. *Transactions American Foundrymen's Association*, 1928, pages 439–452.
[17] H. W. Gillett & E. L. Mack. The Electric Brass Furnace Refractory Situation. *Journal American Ceramic Society*, Vol. 7, 1924, pages 288–299.
[18] William Adam, Jr. The Ajax-Wyatt or Vertical Ring Induction Furnace. *Transactions American Electrochemical Society*, 1930, pages 443–466.
[19] D. F. Campbell. Recent Developments in Electric Furances. *Journal Institute of Metals*, Vol. 41, 1929, pages 37–72.
[20] A. G. Robiette. The Low-Frequency Induction Furnace and Its Scope. *Metallurgia*, Vol. 3, 1931, pages 175–176.

Coreless or High-Frequency Induction Furnace

In the coreless induction furnace, metal in a crucible is melted by its own resistance to an electric current induced from a winding surrounding the container. Commercial furnaces from a few pounds to 1-ton capacity are successfully melting a wide variety of alloys, ranging from silver to alloy steel. Furnaces of $3^1/_2$-tons capacity are expected to be used for melting steel in the immediate future.

For good electrical efficiency, the furnace walls through which the electric current passes must be thin. The molten metal is circulated rather rapidly by the effects of the electric current. The lining must be impervious to metal penetration and, hence, dense and free from cracks. It should not have high thermal conductivity. For melting steel it must have high refractoriness.

Prefired crucibles are used, but are not required and have been found less satisfactory than rammed-in, monolithic linings.[21] According to Northrup, pure silica sand, of which about 15% has been finely pulverized, tamped dry around a form, and sintered in place around a steel core, makes a suitable acid lining for use below 2900° F. A lining made of pure zircon ($ZrSiO_4$) sand, prepared as is the silica lining with 15% fine powder, has the good qualities of the silica lining and is more refractory. Such a lining has proved satisfactory[21] for making steel and super-heated cast iron. Linings prepared in this manner remain unsintered a short distance outward from the inside and thus are better heat insulators than linings that have been completely sintered.

For basic linings, some form of magnesia is employed. Magnesite which has not been completely shrunk causes difficulties which are overcome by the use of electrically sintered magnesia. Magnesia linings, however, are subject to growth which might damage the inductor coil. This growth perhaps is due to the absorption of iron oxide from the charge, as it is known that periclase (MgO) will take up in solid solution large amounts of Fe_2O_3, enough, in fact, to form the compound magnesioferrite ($MgO{\cdot}Fe_2O_3$).[22]

[21] E. F. Northrup. Tonnage Melting by Coreless Induction. *Iron Age*, Vol. 127, 1931, pages 228–233.
[22] Wm. J. McCaughey. Private Communication.

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Standard Steel Samples

The U. S. Bureau of Standards has prepared a standard sample of high sulphur steel (0.60% sulphur) containing 0.193% carbon. This steel, though not of a commercial grade, was specially prepared to provide a standard sample which would serve to meet all conditions encountered in carbon determinations on commercial high sulphur steels. This standard, which is No. 105 in the series and certified for carbon only, costs $1.00 per sample of 150 grams. The sample may be paid for in advance with the order, or be sent parcel post C.O.D. in the United States and its possessions. All foreign shipments require prepayment, together with 20 cents additional postage.

The Bureau of Standards is also preparing a standard analyzed sample of Nitralloy "G" Steel (approximately 1.3% chromium 1.1 aluminum, and 0.20 molybdenum) which will be available for distribution about February 1, 1932.

A complete list of standard samples, analyses, fees, etc., are given in Bureau of Standards Supplement to Circular No. 25, which can be obtained free of charge upon application to the Bureau of Standards, Washington, D. C.

Fig. 1

SILICON CARBIDE and Its Application in Metallurgy

BY H. R. HOUCHINS* AND C. McMULLEN*

As THE type of refractory material used in metallurgical furnaces is a large factor in the efficiency and life of the furnace, it is obvious that although a metallurgist is not particularly interested in ceramics in general, he should have some knowledge of refractory materials and their use in metallurgical furnaces. During the past few years many new alloys and metallurgical processes have been developed, creating a need for a similar advance in the refractory field to meet these new requirements. This was necessary because no one refractory material could be used to answer every problem, and because a special refractory must be designed to meet special requirements.

This point can be illustrated by the basic open-hearth furnace, the arch of which is composed of silica brick. This acid refractory is used for the purpose because of its high coefficient of expansion which strengthens the arch on heating. The hearth itself is lined with magnesite, a basic material being required for this basic steel process.

There are many different ceramic materials used as refractories, each having a particular set of physical and chemical properties to cope with a certain problem in which some other material would fail. Silicon carbide is one of these materials and has a combination of physical and chemical properties which no other refractory can duplicate. It is therefore used in many different types of metallurgical furnaces where other refractory materials have failed or given poor results.

At the present time electric furnaces seem to be increasing in favor in the field of metallurgy. Here silicon carbide has a place as an electrical resistance element which can be used where carbon or metallic resistors would be impracticable. Silicon carbide is practically unaffected by furnace conditions at temperatures where ordinary metallic resistors would melt or carbon resistors would oxidize rapidly. The silicon carbide resistors will operate without trouble up to the usual limits of heat treating furnaces. Operating temperatures up to 1400° C. are easily obtained with these resistors.

* Engineer, Research Laboratory, The Carborundum Co.

From the following table it can be seen wherein the qualities of silicon carbide differ from those of other refractory materials. Some specific refractory applications are given later with the reasons why it is employed in preference to other materials.

As can be seen from the table the most important properties of silicon carbide refractories advantageous to metallurgical applications are the high thermal conductivity, great refractoriness, high strength, excellent resistance to mechanical and flame abrasion, and freedom from spalling.

APPLICATIONS

Heat Treating Furnaces

Bonded silicon carbide has been found ideal for muffle furnaces designed for hardening high speed steel. Since its heat conductivity is nearly 10 times that of fire clay, the charge is heated more quickly and more evenly and the production increased. The fuel saving over fire clay often runs as high as 20%. Also in larger furnaces a more uniform temperature is maintained at all parts of the furnace chamber. A heavily loaded carburizing furnace of the semi-muffle type with a clay floor will be considerably hotter at the top than on the floor. This condition can be corrected by using a silicon carbide floor.

The use of silicon carbide hearth tile and supports in

heat treating furnaces is now practically standard practice because clay will not stand the elevated temperatures in these small furnaces for any appreciable length of time. Clay hearths soon crack and become "tacky." As a result, the dies or other ware being heated leave indentations in the clay hearths so that the hearths have to be patched for subsequent operations. The patching cement frequently adheres firmly to the ware. Silicon carbide hearth tile and supports have justified their somewhat higher initial cost many times over in this heating application and have eliminated the difficulties mentioned, as well as giving up to 15 times the service life of the clay materials.

It has been found that when a clay floor is used in hardening large die blocks, cold spots are often found under them, and the blocks must be turned several times to insure even heating. The silicon carbide floors have overcome this difficulty to a large extent, and also their great strength eliminates any danger of the ware going through the floor. The same general situation exists in carburizing furnaces where alloy pots are used. The silicon carbide floors prevent sticking and eliminate cold spots under the pots. The high mechanical strength allows the use of much thinner sections in the furnaces. The non-spalling character of the silicon carbide eliminates cracking and chipping of the floor and supports when cold stock is placed in a hot furnace.

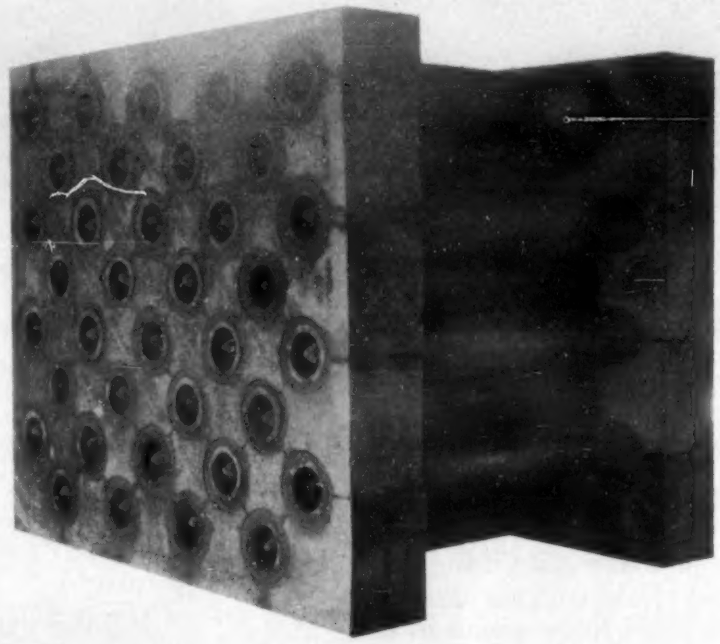


Fig. 2

In heat treating and annealing stainless steel a silicon carbide muffle has been found especially useful since a uniform temperature may be obtained and the atmosphere of the heating zone is easily controlled.

Iron Melting

The chemical nature of silicon carbide limits its use here to some extent. For example, its use is not recommended in cupola furnaces melting iron because the strong fluxing action of any iron oxide present results in the formation of complex iron-silicon compounds with destruction of the silicon carbide and contamination of the furnace product as well.

Non-Ferrous Metals

Both bonded silicon carbide and cements containing a large percentage of the carbide are used in the processing of non-ferrous metals. In this field a refractory is required that will stand high temperatures and abrasive or corrosive action. Silicon carbide retorts for the distillation and purification of zinc have been found to to stand up better than any other refractories used. The brick and shapes for this work must have a low permeability to prevent entrance of zinc fumes since one of the chief causes of disintegration in zinc retorts is the corrosive action of the vapors.

Probably the greatest use of silicon carbide cement is found in the manufacture of brass. This cement is rammed into the linings of crucibles or furnaces in a plastic condition and then slowly dried. This lining is vitrified by heating the furnace so that a monolithic piece is formed. In the tilting or rotary type furnace these linings are subjected to the severest possible conditions due to abrasive action of the metal against the lining. Quite often it has been found advantageous in this type of furnace to apply a glaze to the lining so that during the first heat the interior acquires a smooth dense surface. This tends to keep the granular refractory material from loosening and contaminating the melt.

The use of silicon carbide supports for the crucibles in crucible type melting furnaces has proven very satisfactory. Lids of the same material have replaced clay lids in many cases as they give a longer life and have the big advantage that the center hole in the lid does not get larger due to flame action or mechanical abrasion such as happens when clay is used.

Use of Silicon Carbide in Graphite Crucibles

Silicon carbide has come into extensive use in the manufacture of graphite crucibles. The usual mix for foundry crucibles contains natural graphite, silicon carbide and a binder. The operating life of a graphite crucible is greatly prolonged since the silicon carbide

	Apparent Density	Specific Heat[1] Mean 0–1000° C.	Thermal conductivity in g. cal./cm.[3] °C./sec. between 0° & 1000° C.	Compressive strength lbs./in.[2]	Spalling loss—ten heats to 1300° C. with sudden air cooling after each[3]	Loss by abrasion against grinding wheel for 5 min. at 25 lb. pressure (inches)[4]	Electrical Resistance in ohms per cm.[3] (except where megohms are indicated)[5] 20° C.	800° C.	1200° C.	1500° C.	Transverse breaking strength lbs./in.[2] modulus of rupture at 1350° C.[6]
Recrystallized silicon carbide	2.30	0.26	0.040 [1]	12,500*	12%	0.01	107	6.5	2.45	1.62	2437
Bonded silicon carbide	2.45	0.26	0.038 [1]	14,700*	6	0.02	107,200	12,500	4,160	745	900
Silica	1.66	0.26	0.005 [1]	2,300*	100	0.17	125 meg.	2.38 meg.	62,000	8420	160
First quality fireclay	1.78	0.26	0.0035 [1]	1,050*	9	0.26	137 meg.	57,600	4,160	890	113
Chrome	2.83	0.17	0.003 [2]	3,900*	100	0.07	48 meg.	803	0.63	41	22
Zirconia	3.30	0	....	.....	55	0.02	134 meg.	558,000	7,710	412	..
Magnesia	2.27	0.26	0.012 [1]	4,800*	100	0.05	137 meg.	5 meg.	193,000	2500	136
Bauxite	1.91	..	0.0033 [2]	.....	43	0.02	133 meg.	109,000	6,100	1100	99
Quartzite			0.0026 [2]								

* Best available values subject to revision.
[1] Hartmann & Westmont. *Transactions American Electrochemical Society*, Vol. 50, 1926, page 126.
[2] Wologdine. *Electrochemical & Metallurgical Industry*, Vol. 7, 1909, page 382.
[3] Hartmann & Hougen. *Transactions American Electrochemical Society*, Vol. 37, 1920, page 707
[4] Hartmann & Kobler. *Transactions American Electrochemical Society*, Vol. 37, 1920, page 717.
[5] Hartmann, Sullivan & Allen. *Transactions American Electrochemical Society*, Vol. 38, 1920, page 279.
[6] Hartmann & Koehler. *Transactions American Electrochemical Society*, Vol. 40, 1921, page 457.

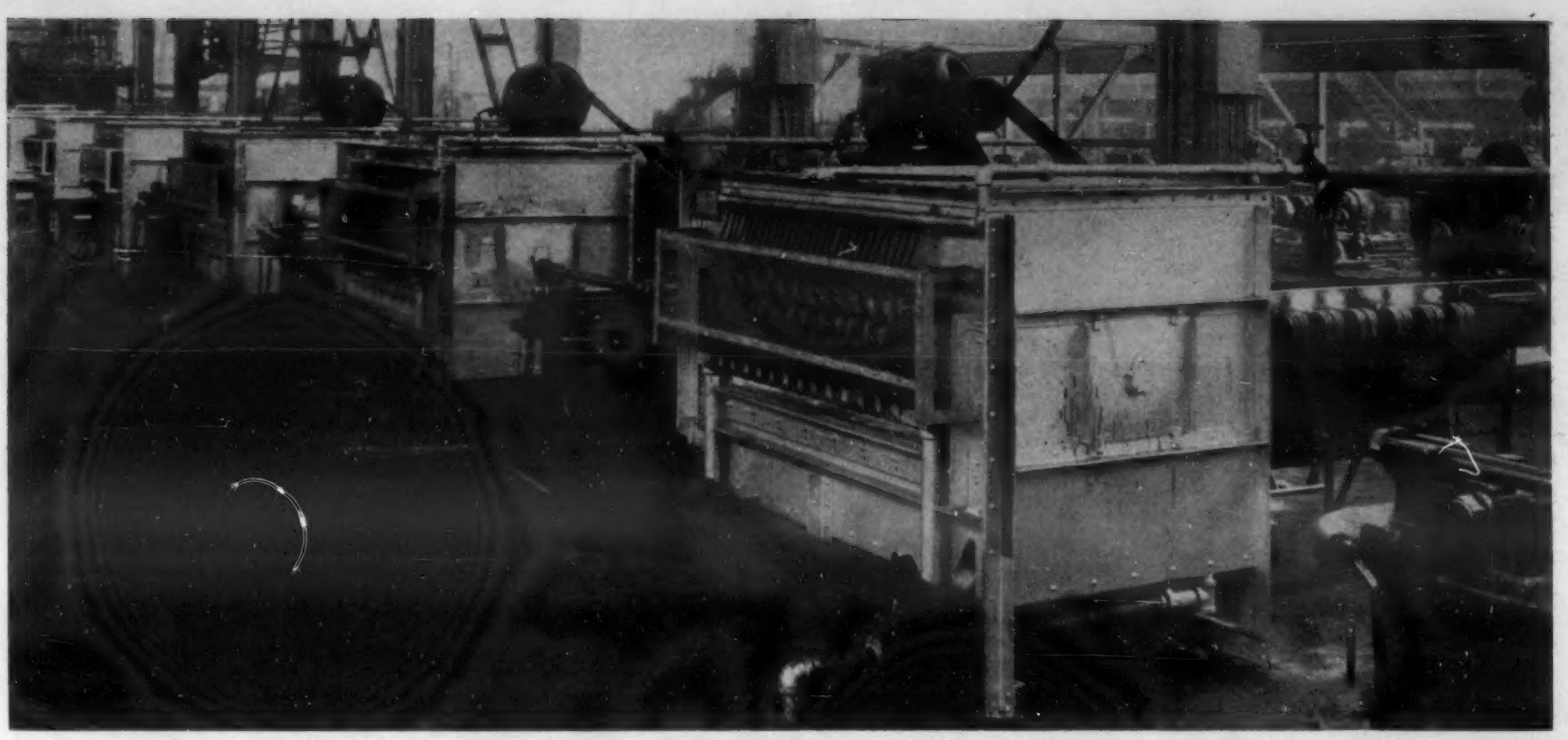


Fig. 3

increases the mechanical strength of the crucible and its resistance to oxidation. Silicon carbide is a good heat conductor, highly refractory and not easily reduced in the presence of carbon at high temperatures.

Recuperators

Bonded silicon carbide with its high heat conductivity and its resistance to sudden temperature changes is particularly adapted for use in recuperative installations where a large volume of air or gas is to be preheated. The air to be heated is passed through tubes made of this refractory while hot exhaust furnace gases pass over the outside of the tube. In this way considerable heat can be saved.

The main advantage of the silicon carbide recuperator tile is that it is able to operate at a much higher temperature than a metallic tube. A temperature of preheat is secured which cannot be attained otherwise and as a result a higher furnace temperature is obtained.

It has been found that on open-hearth steel furnaces, silicon carbide recuperators are replacing the regenerators now in use because the silicon carbide can operate at the temperatures encountered and last through a full campaign. Regenerators or the older type recuperators had difficulty in running the full length of an open-hearth siege and had to be rebuildable for that reason. Rebuilding limited and hampered the furnace operation so that the full time silicon carbide heat recovery device has been found a distinct step in advance. Fig. 2 shows the inner parts of a recuperator installation with the bank of tubes set in end walls ready for connection to the air and flue gas supplies.

"Carboradiant"* Furnaces

These consist essentially of a heating chamber by which the furnace itself is heated. The fuel, which may be oil or gas, is injected with the combustion air into the silicon carbide refractory chamber. As combustion takes place the heat is liberated rapidly and uniformly through the chamber. Rapid perfect combustion is possible since the refractory will easily withstand the high temperature necessary. At the same time heat is not stored up to a point where the refractory is damaged.

It has been found that combustion may be kept perfect over a wide range of temperatures and rates of fuel feed. The atmospheric conditions may be controlled in the furnace to give an oxidizing, neutral or reducing condition while at the same time there is an entire freedom from soot or smoke in the furnace proper. Of course, a completely muffled condition can be arranged to prevent the products of combustion coming in contact with the ware if so desired.

Fig. 1 shows the "Carboradiant" method of heating a carburizing furnace. The heating chambers run along each side of the furnace from back to front.

Pyrometer Tubes

Tubes made of bonded silicon carbide are useful as protection tubes for thermocouples. The metal couple wires cannot successfully be used in direct contact with the silicon carbide tube at high temperatures. However, at high temperatures, the silicon carbide acts as a support and protection against slag for the regular porcelain tube containing the couple wires.

Silicon Carbide as a Heating Element

It can be seen from the table of data that silicon carbide is the only refractory material which will conduct electricity at ordinary voltages. This fact led to its use as a resistance element in electrically heated furnaces. These resistors are now perfected and are designed to operate at voltages of 55, 110 or 220 so that no special transformers are needed. Temperatures as high as 1500° C. may be attained with these non-metallic resistors. Temperatures even higher have been reached in small laboratory furnaces, but at the proportional expense of the life of the element. Since this non-metallic resistance element was invented, its principal use has been in metallurgical furnaces such as those for forging and heat treating. Great flexibility of design is possible because of the variety of sizes, lengths and electrical properties, in which these heating units can be made. The advantages of this heating unit over coal or fuel oil are evident because the furnace atmosphere is more easily controlled, there are no fumes and smoke with which to contend, and automatic temperature control is easy. Shop conditions are greatly improved due to the clean compact units which require no fume hoods, fuel lines, blowers and the other usual equipment. The Fig. 3 shows a typical installation at one plant of a large automobile manufacturer.

* "Carboradiant" is a registered trade-mark of The Carborundum Company.

The ALUMINO-SILICATE REFRACTORIES

BY G. A. BOLE*

ALUMINO-SILICATE refractories in the broadest meaning of the term include the fire clay, diaspore and kaolin refractories, as well as the sillimanite group, both natural and artificial.

One might properly think of refractories as rocks, which is to say they are bodies in which various minerals are bonded by a cementitious material, usually a glass. The petrographer thinks of them in terms of components existing in various phases, each phase being or having at one time been in thermo-chemical equilibrium with the various other phases with which it is associated, (if they are compatible phases). These various phases are seldom pure minerals but take into solid solution other co-existing phases until saturated under the temperature and concentration conditions existing at the time.

The fact that the various solid and compatible phases will form liquid phases (eutectics) with each other is the all important consideration in the bonding of refractories and in the resistance which a given refractory will offer in service to a given slag.

Where a service demands that a refractory be bathed by a given slag, it is difficult to classify the refractory in terms of service except by actual trial. No slag test has as yet been developed which can safely be used in a purchase specification, although some progress has been made toward simulative service tests.

Although we are far from being able at present accurately to judge whether a given refractory will resist slag attack better than another rather similar refractory, a study of the various equilibrium diagrams will help ine valuating a refractory for a given service if the conditions of service are accurately known, but the trouble here is the conditions of service are not accurately known and so few systems have been worked out beyond three components, while in the ordinary smelting practice many components are usually involved.

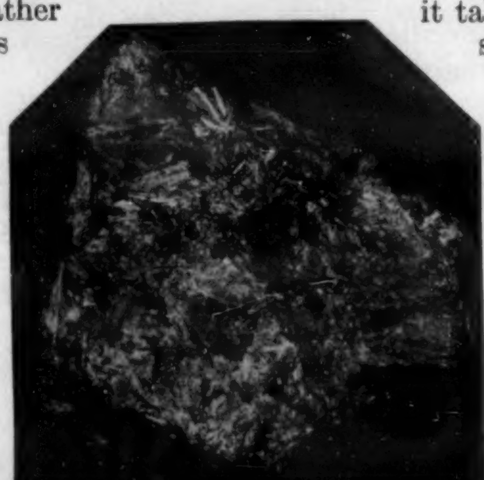
* Research Professor of Ceramic Engineering, Ohio State University.

As our knowledge of the thermo-chemical reactions involved increases, such observations will doubtless be of real value in choosing a refractory for a given service.

The metallurgist works to produce a liquid slag with given solution characteristics, while the refractories manufacturer seeks to produce a solid body which will resist solution. Since the number of minerals which are sufficiently refractory to serve as furnace linings are at best limited and since the conditions demand not only refractoriness but also set up a very definite set of thermo-chemical conditions the problem becomes difficult. In addition to these demands and often quite as important is the fact that these linings must resist heat shock as well as slag attack and must in many cases possess special properties such as high heat conductivity or a certain electrical conductivity; the problem is indeed involved. But as if all this were not enough the demand is made that the product come within a given price limit.

I take it that the ideal refractory for lining a metallurgical furnace would be a product which would be a single mineral of nil porosity, low thermal conductivity, no thermal expansion and existing in one phase throughout the entire temperature range or if it exists in several phases these phases should all have the same specific volume and similar crystal configurations. The mineral should not be affected by furnace atmosphere and should be insoluble in the slag, nor should it take the slag or any component of it into solid solution. It should melt congruently. Such a refractory would resist slag and thermal change ideally. Having all these characteristics it would still not be the universal refractory, since other specific characteristics are often desired, as thermal or electrical conductivity. Every furnace man knows that even such a refractory would have to meet a certain price.

The alumino-silicate refractories



Crude lump of Sillimanite.

(Left) Unloading from Wagon on the Keyline of the loading berth at Calcutta.

(Right) Reloading into Iron Buckets and Hoisting by Ship's Derrick Crane.

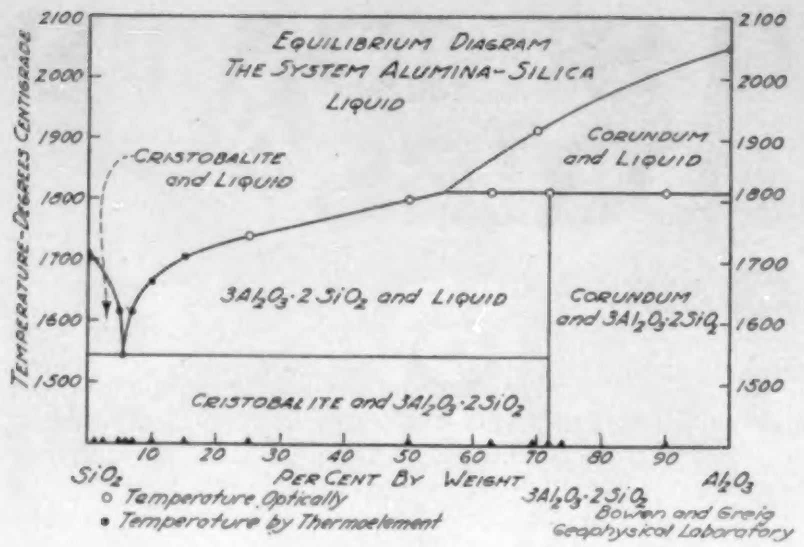


Fig. 1

do not meet all the demands mentioned and they vary widely among themselves, but they do meet certain demands better than any other type of available refractory. The basic causes underlying their failure to meet all the demands of the ideal refractory can be best outlined by looking into some fundamental thermochemical considerations.

It is customary and we believe profitable to preface a discussion of the alumino-silicate refractories by a presentation of the equilibrium diagrams involved. Having in mind the fact that two compatible phases will each generally lower the fusion point of the other when co-existing in a given system, and knowing that if a third phase be added there will be an eutectic between the three phases, having a melting point lower than that existing between the two phases, and that a fourth phase will further lower the temperature at which the first liquid may appear, it becomes evident that the multiple phase systems are likely to be the less satisfactory refractories, so far as slag attack is concerned, which is another way of saying that a refractory composed of many minerals is likely to be less satisfactory than one made from a single mineral. The ordinary fire clay refractories fall within the field of multiple phase systems and are used primarily on account of their favorable price. Pure clays such as the kaolins are more refractory than the less pure fire clays due to the same reason and the so-called sillimanite group of refractories are still more refractory, since they are a simpler phase system.

Clay is essentially hydrosilicates of alumina and if it were not for the impurities always present would constitute the two component system shown in Fig. 1, due to Bowen and Greig. The diagram shows the effect of adding silica to alumina and vice versa in all proportions and their action upon each other when subjected to heat. If a particular composition represents a mineral, as does the composition 28.2% silica and 71.8% alumina, an interesting point is raised. We see that the eutectic at 94.5% SiO_2 and 5.5% alumina is not an eutectic between alumina and silica but between this mineral (mullite) and silica (cristobalite). Mullite is the only alumino-silicate stable at high temperature. An additional interesting feature of mullite, as will be seen from the diagram, is that when a temperature of 1810° C. is reached it melts incongruently, that is to say it does not melt as a unit, but forms a solid (corundum) and a liquid. The diagram shows that any mixture of alumina and silica under 71.8% alumina and 28.2% silica, when heated to 1545° C., will form a liquid, the amount of liquid depending upon the oxide ratio. This fact explains why these compositions have a softening range rather than a true melting point. Any compositions higher in alumina than 56% will melt incongruently above 1810° C., the solid phase being corundum. All of these relations, of course, assume a condition of equilibrium between the phases. These conditions will actually obtain only when the system has been held at the given temperature for a considerable period of time or when the liquid mass is slowly cooled.

We stated that mullite ($3\ Al_2O_3 \cdot 2\ SiO_2$) is the only stable mineral formed by alumina and silica at high temperatures. There are several alumino-silicate minerals stable at ordinary temperatures, and strange to say, they all have the same oxide ratio, namely, 1 : 1. Sillimanite, andalusite, and cyanite all have an oxide ratio of $SiO_2 : Al_2O_3$. Their chemical composition is 38.1% SiO_2, 62.9% Al_2O_3. All these minerals invert to mullite upon heating and upon reaching 1545° C. sweat out a highly siliceous liquid. Bowen and Greig point out an interesting difference between the behavior of the natural minerals and an artificial combination of the same oxide ratio (1 : 1).

"At temperatures not far above the eutectic (1545° C.), crystals of natural sillimanite appear to change less readily than the 1:1 artificial mixture. This apparent difference is due to the contrasted structure of the two materials. The 1:1 mixture, even before being raised to a temperature above the eutectic, already consists of two phases, cristobalite (silica) and $3Al_2O_3 \cdot 2SiO_2$, in random arrangement. When this aggregate is heated to a temperature above the eutectic the cristobalite disappears and the liquid formed constitutes a matrix for the minute prisms of $3Al_2O_3 \cdot 2SiO_2$, still, of course, in random arrangement. On the other hand, natural sillimanite is a single, pure, crystalline phase and therefore perfectly homogeneous. Moreover the difference in crystal structure between sillimanite and mullite ($3Al_2O_3 \cdot 2SiO_2$) is so slight that when liquid and crystals of $3Al_2O_3 \cdot 2SiO_2$ are formed from sillimanite the new-formed crystals are coextensive with the original grains of sillimanite and of identical orientation. The liquid occurs as minute pellets and filaments in the large grains of $3Al_2O_3 \cdot 2SiO_2$. Mechanically the aggregate formed from natural sillimanite is probably the stronger because the crystalline phase is the external phase, whereas the liquid phase is external in any synthetic 1:1 aggregate. At temperatures far above 1545° C., however, where the amount of liquid is much increased, the difference between the two types of material is not so great but it is still noticeable at 1750° C.

"We thus see that natural sillimanite may, perhaps, have certain advantages over an artificial 1:1 mixture in a mechanical way; though not fundamentally any more refractory, but whether this difference observed in our small charges would be sustained in actual use under load our work does not enable us to state."

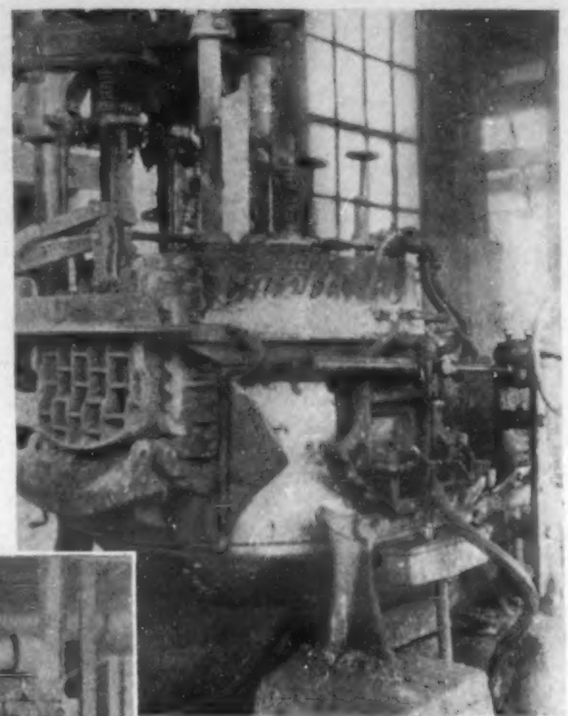
The natural minerals sillimanite and andalusite are mineralogically quite similar to mullite—the fact is, sillimanite is easily mistaken for mullite even upon microscopic examination. Cyanite has very different physical properties, however. It crystallizes in a different system and has a very considerable volume change in going to mullite, so great, in fact, that unless heated with great care it will rupture any body made from it. This characteristic of cyanite has been taken advantage of in an endeavor to compensate for the high temperature at which shrinkage of such clay as the diaspores by adding a small amount to the green ware, which will expand upon heating at about the temperature the diaspore starts to shrink. If the cyanite is precalcined, it produces a refractory quite similar to the andalusite refractories.

So-called sillimanite refractories, which are really essentially mullite, are made in two different ways, either by melting the properly proportioned oxides in an electric furnace and allowing the cast mass to cool slowly, as in the case of Corhart refractories, or by bonding the natural minerals, cyanite and andalusite with a plastic clay and firing to about 1400° C. The Charles Taylor Sons Company uses a rock imported from India which is essentially cyanite and the Champion Porcelain Company uses andalusite and another alumino-sili-

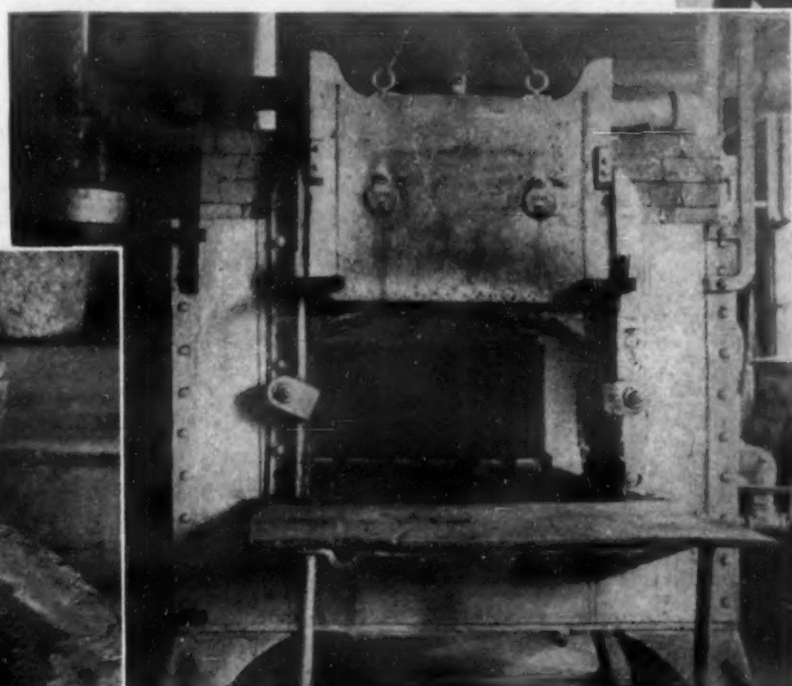
cate containing a molecule of boric oxide, demortierite, obtained from the western part of the United States. All these are rock formations, quite pure, as they occur in nature. Cyanite bearing schists are concentrated at two points in the eastern United States, where a high grade cyanite is recovered.

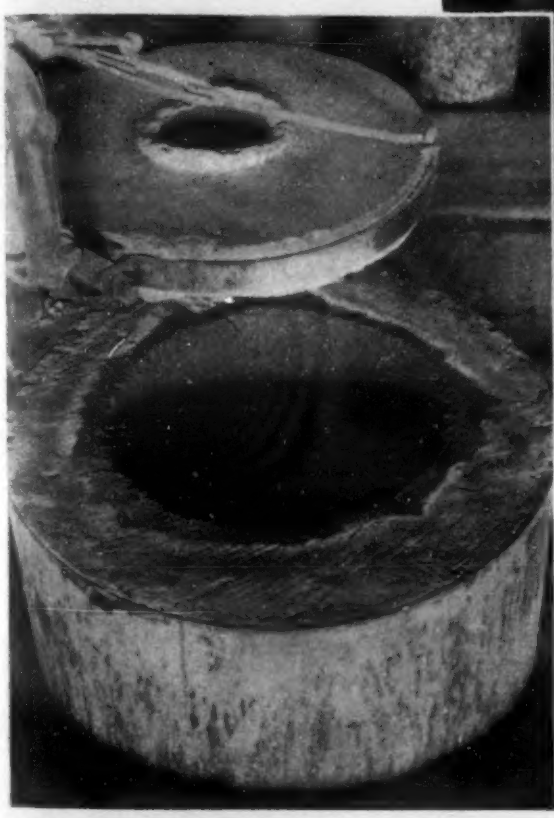
The other great source for so-called aluminous refractories is the diaspore fields of Missouri. Diaspore refractories are made by a majority of the larger refractories companies. Diaspore is a mineral having the theoretical composition $Al_2O_3 \cdot H_2O$. The Missouri deposits are not the pure mineral, but are a highly aluminous clay containing diaspore in varying amounts. The composition of the refractories made from them vary all the way from 50% to 80% Al_2O_3. They are not usually spoken of as diaspore refractories until the alumina content has reached 60%.

The diaspore goes slowly to corundum upon heating at the kiln temperatures and practically the same reactions occur in this type of refractory as in the ordinary alumino-silicate as described above, except that there is a certain time lag which under certain conditions is very pronounced. It should be borne in mind that these reactions described are equilibrium reactions and that they occur only at contact surfaces of the reacting phases, so may be very slow, especially if the grains are large or if the glass phase is viscous. In the maturing of the diaspore refractories there is another consideration of importance—namely, the reluctance of one crystal phase to invert to another. If the free alumina (over the mullite ratio) in diaspore refractories could be converted to β-corundum instead of α-corundum, which is its normal habit, we would have a refractory subject to less volume change, since the β-form has nearly the same specific gravity as diaspore. Some attempts have been made to speed this action by the addition of such mineralizers as phosphoric and boric acids. The sluggish transition of diaspore to corundum and the reluctance of the solid phases to react to form mullite likely account for the shrinkage of diaspore refractories in service.



(Top) Direct Arc Electric Furnace with Sillimanite Roof, Side Walls and Hearth.



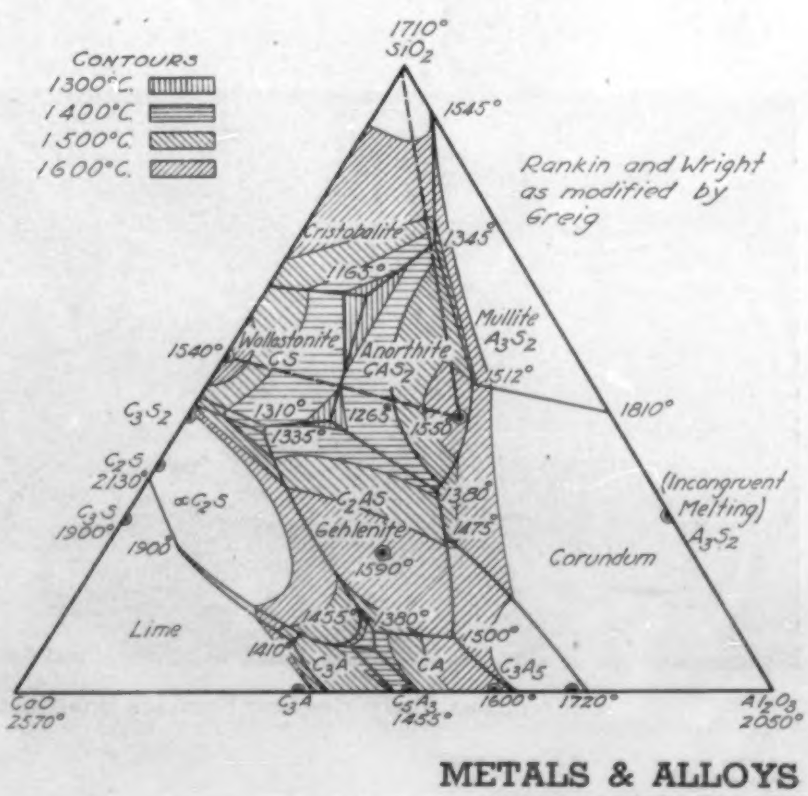


Underfired Heat Treating Furnace with Sillimanite Hearth. (Left) Crucible Furnace with Sillimanite Monolithic Lining.

The kaolin refractories such as the Babcock and Wilcox product are not essentially different from the alumino-silicate refractories made from andalusite so far as their reaction under heat conditions are concerned except that kaolin has a higher silica to alumina ratio thus giving more glass phase as the temperature is advanced above 1545° C.

The ordinary fire clay refractories have so many incidental minerals present and in such large proportion, and so many of the minerals are active fluxes, that we have a very complicated thermochemical relation. Fire clay refractories will soften under a high load under 1000° and at 1350° C. under a load of 25 lbs./in.[2] will show a slump of several percent in a very short time. Slumping under load is caused by a slow flowing of the glass phase.

In order to illustrate the effect of adding a single mineral to a pure alumino-silicate refractory, the triaxial diagram Al_2O_3-SiO_2-CaO is shown below.



The hatched areas have as their boundaries iso-thermal lines outlining the liquid areas; they mark the shores of the iso-thermal lakes. If another component were present, it would form phases which would cause the areas of these iso-thermal lakes to increase as well as lower the temperature at which the first liquid would appear on heating the system. The rigidity of a refractory of this type would depend upon the amount of glass present at a given temperature, and upon its mobility.

It will be gathered from the preceding discussion that we can consider the alumino-silicate refractories to be constituted of two or more minerals which react at the firing temperature to form a certain amount of a liquid (glass) phase which serves to bond the mineral structure. From this glass phase grow crystals of mullite which serve to develop slowly a crystal bond as well as a glass bond. The refractory in service tends to become a well knit mass of minerals in equilibrium at the furnace temperature.

While we have been stressing the effect of heat on the mineral system developed in a refractory we must not overstress this action since proper manufacturing practice may add to or detract from the way a refractory will stand up under heat conditions. It is, however, much simpler to improve a tendency of a refractory to spall by altering the manufacturing practice than it is to chance its tendency to erode under slag action.

In general, it may be stated in the case of fire clay refractories that a high fired brick will withstand slag attack better than a mild fired brick, but quite the opposite is the case for spall resistance. The tendency to spall is roughly proportional to the amount of glass present and to its tendency to shatter under temperature change.

There is a very considerable trend toward the so-called plastic refractories and ramming mixes. Some of this type in the alumino-silicate field are quite remarkable in that they are made from pre-shrunk grogs bonded with a very little plastic clay so as to produce a mud which has, in some cases, nearly nil shrinkage at furnace temperature.

Another interesting recent development has resulted in the appearance on the market of insulating brick which are at the same time a high grade refractory. It is proposed to use these brick which are, of course, highly porous, as a furnace lining with only a thin facing of plastic refractory. Remarkable savings in furnace costs and speed of operation should be realized from such a lining if it shows constancy of volume and proves to be sufficiently rugged.

It has been thought best to allow the technical men most familiar with each of the refractories to describe the product. The author is indebted to these men for their fine coöperation in furnishing the following information.

FUSED MULLITE REFRACTORIES

Mr. F. W. Schroeder of the Corhart Refractories Company describes Corhart Cast Mullite as follows:

Method of Manufacture

The process consists in its essentials of the introduction of a mixture of several clays of high-alumina content into the top of an electric furnace, from which molten aluminum silicate is tapped at intervals into molds built from sand slabs. The molds containing the case blocks are sent to storage where they anneal for from 6 to 10 days before the blocks are removed to final storage or shipment. Behind this sequence of apparently simple operations lies the customary long period of developmental difficulties and a present system of accurate control.[1]

Chemical Analysis and Microstructure of Product

The chemical composition naturally varies somewhat from time to time. The chief variation is in the silica content, and we are able with our present methods of batch control to regulate this within $\pm 1\%$. The complete analyses given below were made by Mellon Institute and are entirely representative.

	No. 1	No. 2
Silica	20.64	20.53
Alumina	73.65	73.43
Iron Oxide	0.77	0.97
Titania	3.43	3.37
Lime	0.13	0.10
Magnesia	0.24	0.24
Alkalies	1.38	1.44

The mineral composition of Corhart is approximately 55% mullite, 35% corundum and 10% glass. These percentages vary somewhat in different sizes of blocks and with variations of chemical composition.

Physical Characteristics of Product

Corhart Electrocast is such a radical departure from the usual idea of a refractory that laboratory tests are not applicable.

(a) Pyrometric Cone Equivalent—Cone 37–38.

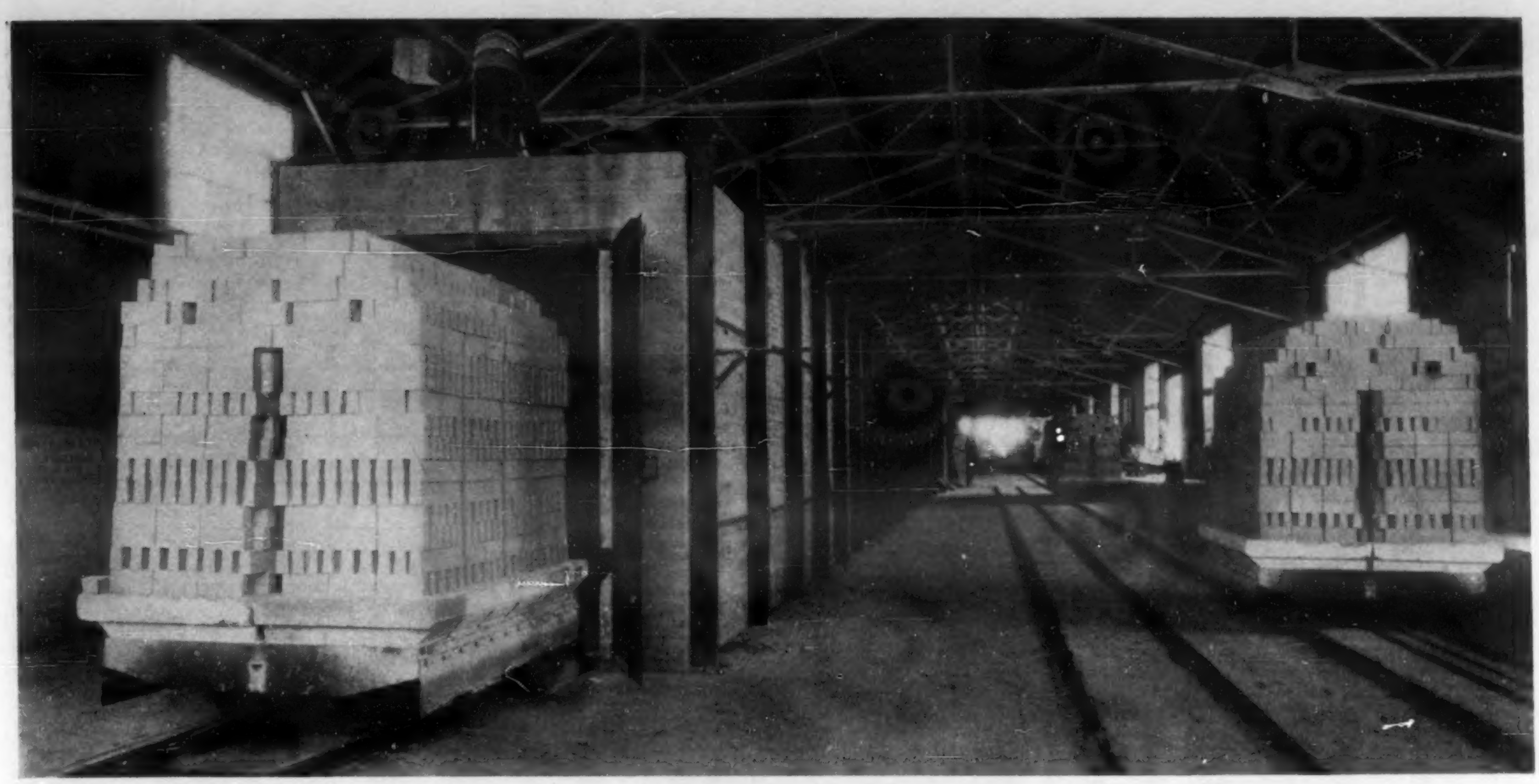
(b) Subsidence under load—A.S.T.M. load test show no deformation to temperatures approaching its fusion temperature.

(c) Spall resistance—Results concerning this characteristic are very erratic. Laboratory tests show Corhart to have very marked spalling characteristics. This result is confirmed by certain service tests. Curiously, in certain other services, where spalling conditions are unusually severe, Corhart has out-performed fire brick.

(d) High temperature shrinkage—Zero, due to the completely vitrified nature of Corhart.

[1] The reader is referred to an article in *Industrial & Engineering Chemistry*, Vol. 23, February 1931, page 124, for a detailed description of the process used in fabricating Corhart Refractories.

Continuous Skelp Heating Furnace lined with Sillimanite. (Courtesy Chas. Taylor Sons Co.)



Discharging End of Car Tunnel Kiln. (Courtesy Harrop Ceramic Service Co.)

(e) Heat conductivity—Undetermined but known to be greater than for fire brick.
(f) Specific gravity—3.2 to 3.4.

Approximate Price and How Merchandised

The price for standard shapes is $200.00 per ton f.o.b. Louisville, Ky. Prices on special shapes are subject to quotation. Corhart is marketed from the factory direct to consumer through a sales force of engineers. The necessity of warehousing is obviated by the rapidity with which the material can be fabricated.

Principal Industrial Application

The principal use of Corhart is in glass tanks. Its use in rotary cement kilns is increasing. Test installations in several types of metallurgical furnaces have given very promising results. Some other test installations have resulted in failures. Corhart is not a cure-all for refractory troubles. It is merely a new material having definitely different physical properties which make it particularly well adapted for many refractory services.

SILLIMANITE REFRACTORIES

Mr. M. C. Booze of the Chas. Taylor Sons Company has described P. B. Sillimanite refractories as follows:

Source and Occurrence of Raw Materials

P. B. Sillimanite is obtained from a surface deposit approximately 100 miles northwest of Calcutta, India. The material is obtained in boulder form, apparently having been broken down from a mother ledge at some other point and transported by water or glacier.

Preparation of Raw Materials

The material as received is in the form of boulders ranging from 10 up to 200 lbs. It is calcined at Cone 14 in 32 ft. periodic kilns, in order to produce inversion to mullite. The boulders are put through a jaw crusher to approximately 3" size and smaller, and later ground in a dry pan to the various screen sizes required, including 4-F, 10-F, 20-F, and 100-F.

Method of Manufacture

9" brick and 9" series shapes are manufactured by bonding the grain with suitable refractory clays, extruding through an auger machine, repressing and burning at Cone 18 in either a gas fired or a forced draft coal fired kiln. Special shapes are manufactured by hand from clay bonded mud.

Chemical Analysis

The chemical analysis of P. B. Sillimanite brick is approximately as follows:

Alumina	59%
Silica	39%
Lime, Magnesia and Alkalies	1.0 to 1.5%

A thin section of the finished product shows a very large quantity of interlacing and sharply defined mullite needles. In this respect it seems to be different from refractories made of artificial mullite or andalusite. P. B. Sillimanite rock is made up of cyanite, andalusite, sillimanite and corundum—the amount of corundum being sufficient to raise the alumina content of the rock to about 66%.

Physical Characteristics of Product

(a) Pyrometric Cone Equivalent—Cone 38. (3350° F.)
(b) Subsidence under load. No deformation in standard load tests, approximately 1% at 2900° F. at 25 lbs./in.^{2}
(c) Spall resistance—Excellent. The resistance of P. B. Sillimanite Ramming Mix to spalling is particularly outstanding.
(d) High temperature shrinkage—P. B. Sillimanite Ramming Mix has no shrinkage from the damp condition to the burned condition up to 3000° F. The burned P. B. Sillimanite brick and shapes at 3000° F. have a shrinkage of approximately $^1/_{16}$" per foot. When made with lower bond content, they have no shrinkage at 3000° F.
(e) Heat conductivity—Practical experience indicates the heat conductivity as being somewhat greater than fire clay, but no specific data available. The specific gravity of Sillimanite after calcining is 3.05 to 3.10.

Approximate Price and How Merchandised

The price of P. B. Sillimanite 9" brick is $500.00 per thousand and P. B. Sillimanite Ramming Mix, $125.00 per ton. The material is sold through representatives in principal cities and by the company's own sales engineers. It is also stocked in Detroit and Pittsburgh in addition to Cincinnati.

Principal Industrial Applications

P. B. Sillimanite is especially adaptable to the service in glass furnaces, crucible furnaces, brass melting furnaces, electric furnaces melting gray iron and steel, forging furnace side walls and roof, under-fired heat treating furnaces, enamelling furnaces, boiler furnaces, combustion tunnels, oil and gas fired fire boxes.

Possibilities in Service

In electric furnace roofs there are cases of twenty times the life of silica. In glass furnaces, superstructure blocks, such as

tuckstones, have been used for two and even three campaigns when made of P. B. Sillimanite, where fire clay refractories ordinarily used are almost completely gone at the end of one campaign.

In furnaces melting brass, P. B. Sillimanite linings have given several times the life of fire clay and this is also true in a number of industrial furnaces operating under severe conditions.

ANDALUSITE REFRACTORIES

Mr. F. H. Riddle describes the available alumino-silicate minerals, their source, preparation and fabrication in an article in the Transactions of the Electrochemical Society, Vol. LIX, 1931. An excerpt from this article follows. Mr. Riddle's company, the Champion Porcelain Company, are makers of andalusite refractories.

"Refractories with an andalusite base have successfully and economically replaced several other high-grade products. Tunnel kiln car tops, saggers, high temperature kiln linings, burner parts, etc., are made from this product.

"In some instances andalusite refractories have been sensitive to heat shock, while in others they have proved extremely good. This refractory is best when exposed to high temperatures, preferably above 1500° C. (2732° F.), as the crystalline growth and resistance to thermal shock improves.

"A properly proportioned andalusite mixture has practically no permanent volume change from the dry to the fired state. The tendency is for a slight expansion. Advantage has been taken of this fact in the manufacture of plastic patching or monolithic construction. This patch has been successfully used to a considerable extent in the lining of electric furnaces of the rocker types, particularly for non-ferrous melts. In the melting of gray iron for casting in an electric furnace of this type, the usual life of a refractory is from 300 to 400 heats. It is interesting to note that a 1000 lb. (454 kg.) installation lined with andalusite has already gone 2,500 melts and is still in service. Andalusite refractories are practically neutral. They are not affected by kiln atmosphere and do not tend to disintegrate through oxidation."

KAOLIN REFRACTORIES

Dr. F. H. Norton of the Massachusetts Institute of Technology has described Babcock and Wilcox Kaolin refractories as follows:

Method of Manufacture

The material used for the B. and W. line of refractories is a pure Georgia kaolin with no additions. In the case of the No. 80 brick, a portion of the kaolin is pre-calcined at a high temperature. The No. 80 brick is manufactured by the regular stiff mud process.

Chemical Analysis

The chemical analysis of the kaolin refractories is as follows:

Silica	52.0
Iron oxide	0.6
Titanium oxide	1.7
Alumina	45.4
Calcium oxide	.1
Magnesia	.2
Sulphur trioxide	.04

Physical Characteristics

(a) Pyrometric Cone Equivalent—Cone 34. (3200° F.)

(b) Subsidence under load of 25 lbs./in.² amounts to 10% at 2900° F. under the regulation A.S.T.M. schedule of heating excepting that the temperature is continued to the higher values necessary for this work.

(c) Spall Resistance—The spalling resistance is unusually high because unlike fire clay refractories the absence of free quartz gives a low coefficient of expansion.

(d) The high temperature shrinkage for the No. 80 fire brick does not start until 2900° F. and is very light at 3000° F.

(e) The thermal conductivity of the No. 80 fire brick is given in the table below:

Mean Temp. ° F.	Thermal Conductivity
1000	12
1500	12.5
2000	13
2500	14

Approximate Price

The approximate price of the fire brick is $260 per 1000.

Principal Industrial Applications

The principal application for the No. 80 brick is under severe conditions where the usual fire brick will not stand up. This includes particularly boiler furnaces, malleable iron furnaces, enameling furnaces, ceramic kilns, etc. The No. 80 brick is particularly suited to conditions of high temperature and load such as for floors, piers, and walls heated on both sides.

DIASPORE REFRACTORIES

Mr. L. C. Hewitt of the Laclede-Christy Company has presented the case of diaspore refractories as follows:

Method of Manufacture

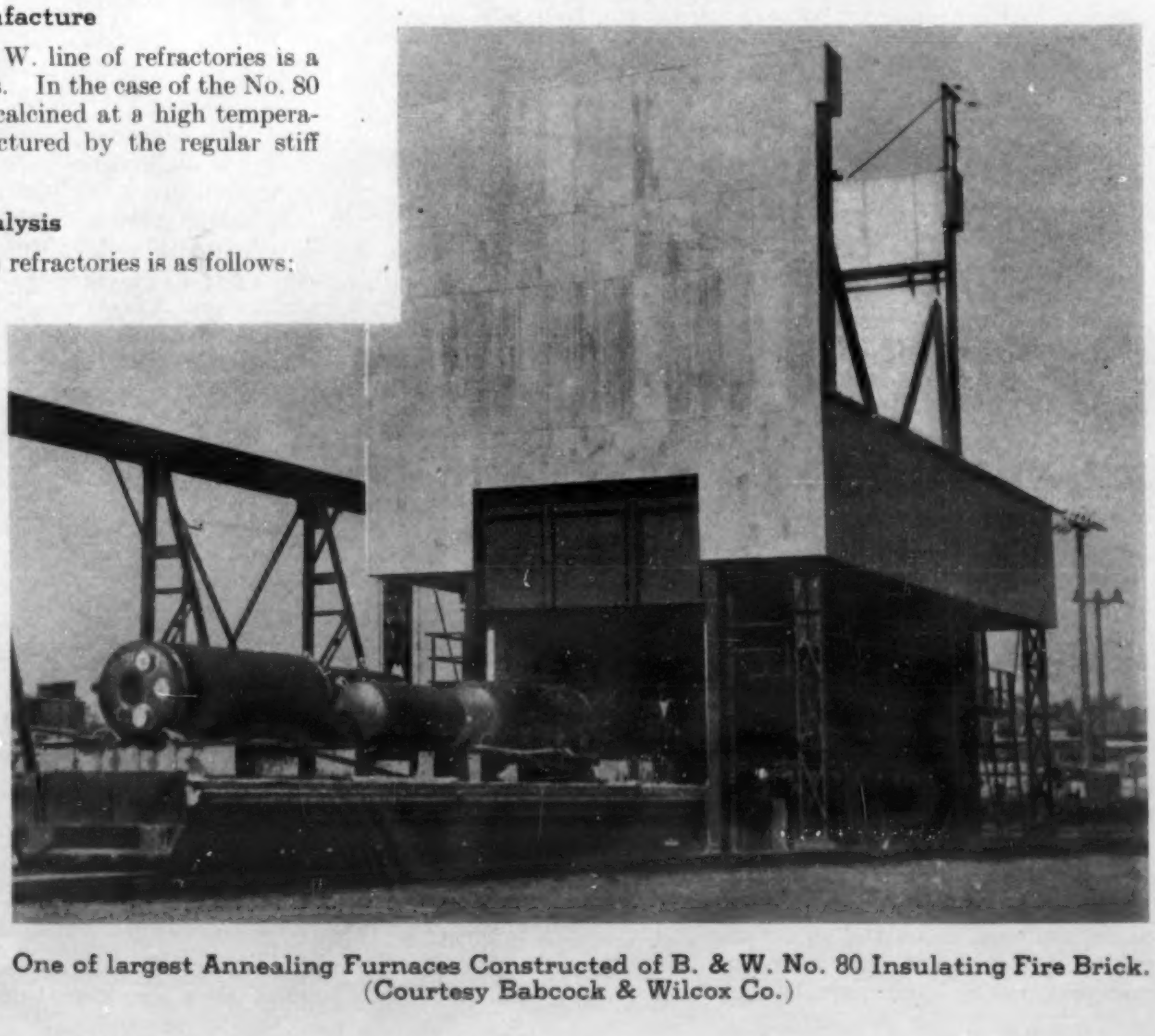
The diaspore clays occur in sink holes in the limestone beds of south central Missouri.

This ore is first sorted and graded according to its quality and alumina content, the latter being based principally upon experience, although the specific gravity method is now also used.

Pre-calcining is resorted to, all the way from about 40 to 80% depending upon the structure which it is desired to develop in the ware.

The fabrication methods do not vary materially from those used for fire clay refractories. The hand, stiff mud, and dry press methods are used depending upon the particular qualities desired. In some instances the hydraulic method of processing is used also.

Generally speaking, the hand-made method is used most extensively for shapes, while the dry press is most commonly used for 9″ brick.



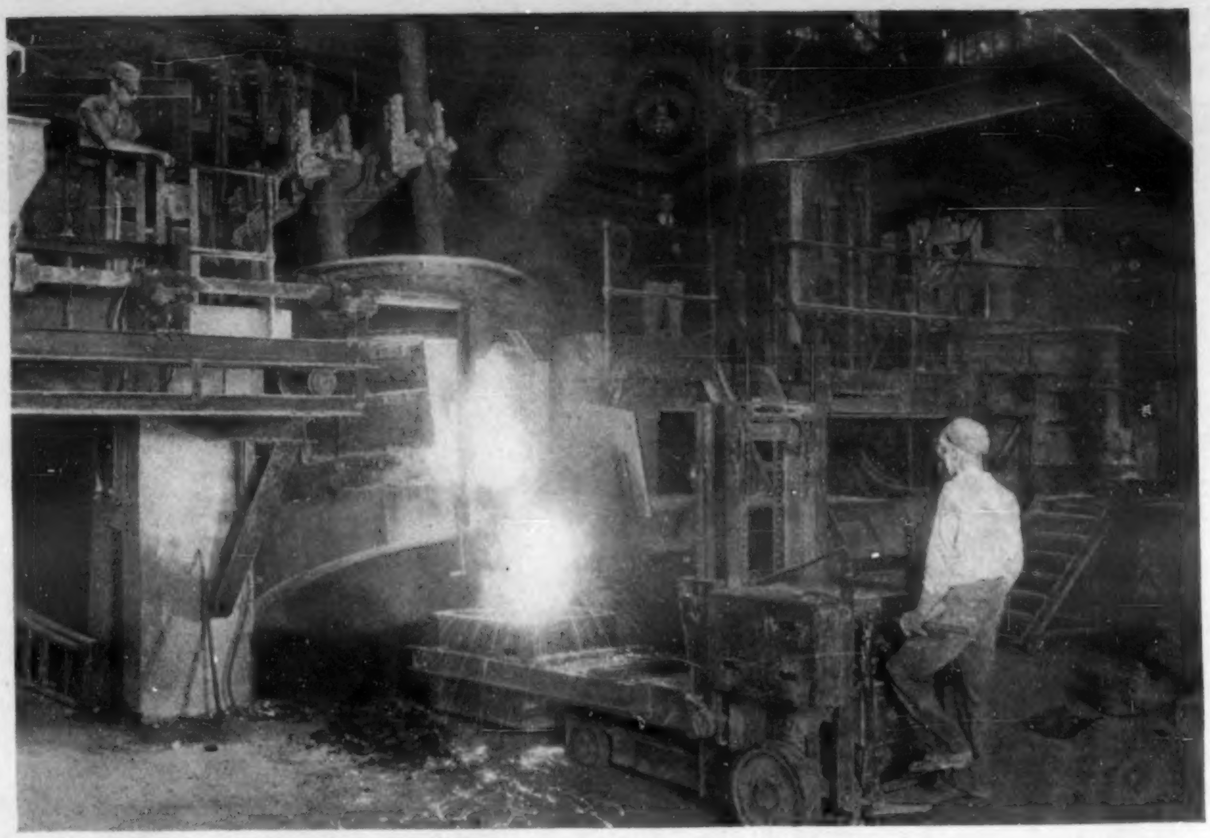
One of largest Annealing Furnaces Constructed of B. & W. No. 80 Insulating Fire Brick. (Courtesy Babcock & Wilcox Co.)

Chemical Analysis and Microstructure of Product

At the present time diaspore refractories seem to be grouped into three classes, viz., those analyzing about 60%, 70%, and 80% alumina. The 70% grade are more extensively used than the others. A typical analysis of such a product is as follows:

Silica	22.12
Alumina	72.11
Ferric oxide	1.45
Titania	3.00
Calcium oxide	0.44
Magnesia	0.44
Alkalies	0.88

In regard to the 60% and 80% alumina grades, the constituents other than silica and alumina would not be very materially different than that of the 70%; in other words, the analysis could be built up by changing the silica content accordingly.



Furnace for Manufacture of Corhart Refractories. (Courtesy Corhart Refractories Company.)

Physical Characteristics

The Pyrometric Cone Equivalent will lie between cone 36–40 for the alumina contents mentioned above; that of the 70% class being cone 37–38. According to the A.S.T.M. method for subsidence under load, the 70% class falls around 2–3%.

While the water dip spalling test does not rate diaspore refractories particularly high, though being above that of first quality fire clay refractories, they do seem to have good resistance to thermal shock, though experience is varied in this respect.

The 70% material would probably average 35 dips before losing 20% by the A.S.T.M. water dip method. The service spalling test, developed by the American Refractories Institute, wherein panels are heated for 24 hours at 1600° C., and spalled 12 times (10 minutes heating at 1000° C. and 10 minutes cooling in an air blast) showed no loss as compared to around 5 to 6% loss for first quality fire clay refractories.

Apparently, high alumina refractories usually spall due to shrinkage, that is spalling is more of a mechanical nature rather than thermal.

Heating one brand of diaspore brick to cone 30 for 5 hours showed a shrinkage of 2.85%. Three tests on one brand of 70% alumina content showed shrinkage of 0.22%, 0.10%, and 1.67%. Another brand of 70% alumina content showed a shrinkage of 3.33% and still a third brand 3.78%.

Two tests on a product analyzing about 80% alumina showed a shrinkage of 2.48 and 1.72%. It seems there is considerable variance not only between brick of the same brand but between brick of different brands.

Phelps in the May 1925 issue of *Fuels & Furnaces*, page 507, regarding refractories for use in checkers states that "diaspore has a heat exchange value equalling that of dense clay brick but evidently a lower thermal conductivity."

A 60% alumina material showed a bulk specific gravity of 2.00 and apparent of 3.08. Two tests on a 70% product showed bulk specific gravities of 2.14 and 2.24 with corresponding true specific gravity of 3.32 and 3.47, whereas two tests on a product analyzing 80% alumina gave a bulk specific gravity of 2.50 and 2.44 with corresponding true specific gravity values of 3.30 and 3.39.

Approximate Price and How Merchandised

Material analyzing about 70% alumina sells for around $145.00 per thousand for 9" brick. Those analyzing higher command a somewhat higher price and a corresponding lower price is obtained for those analyzing around 60% alumina.

These refractories are merchandised in a similar manner to the general line of fire clay refractories, either through agents or direct representation and, of course, also by direct order.

It is also quite common to have a specialties department to promote general use and to coöperate with the consumer, studying service conditions.

Principal Industrial Application

Perhaps the most general use is as a lining material for rotary kilns in the Portland Cement, dolomite, and lime industries. They have been found of advantage in certain boiler installations, though in the main they have not replaced first quality fire clay refractories for this use to any considerable extent.

They have been found satisfactory for certain uses in the lead industry, for dross furnaces and the like, and have quite a wide application in electric brass melting furnaces. Other uses are somewhat varied, such as for burner block and other vulnerable parts of furnaces operated at high temperatures.

High alumina refractories have the quality of easily taking and holding a slag coating (as in cement kilns, etc.) which protects the lining from direct attack. They are also quite resistant to iron slags. Because of their high fusion point they are put to uses where other refractories would fail because of fusion. Their comparatively low cost is another factor in their favor.

Wilson-Maeulen and Foxboro Companies Merge

The Pyrometer Division of the Wilson-Maeulen Company, Inc., has merged with The Foxboro Company. This action has followed twenty-five years of close and friendly coöperation between the two companies, and was made wholly in the interest of better service by thus being able to offer complete instrumentation to industry. The many users of Wilson-Maeulen pyrometers will be served by a larger, more wide-spread group of instrument engineers.

Harry J. Hosking has resigned his position in the research laboratory of the Roessler and Hasslacher Chemical Co. at Niagara Falls, N. Y., to take up similar work with Foster D. Snell, Inc., 130 Clinton St., Brooklyn, N. Y.

W. C. Pinkerton has taken a position as Industrial Representative with Foster D. Snell, Inc. He was previously with the International Exposition Co.

Charles H. Proctor, for almost twenty years Electroplating Specialist of The Roessler & Hasslacher Chemical Company, Inc., retired from active service duty on Dec. 31, 1931, to devote his time to special work for the company, chiefly to assist in training R & H salesmen and also to act as consultant on plating problems. His retirement from active duty comes after more than forty years of association with the electroplating industry, during which time he made many important contributions to the development of the art both in this country and abroad.

Bonding Magnesite Linings

for Steel Melting Furnaces without Use of Iron Oxide*

BY LOUIS JORDAN†

INTRODUCTION

The hearths and banks of basic steel melting furnaces are usually made of dead burned magnesite grain bonded with basic slag or with a commercial bonding material of the general nature of a basic slag.

The first requirement of all magnesite refractories, whether used as bricks or as rammed-in linings is that they must have been fully dead-burned, that is, fired to a temperature high enough to form the crystalline magnesium oxide. A magnesite low in iron oxide requires burning at 1600° to 1700° C. for the development of a satisfactorily sintered lining.[1] It has been customary to use magnesite refractories containing from 5 to 10% of ferric oxide which lowers the sintering temperature several hundred degrees, perhaps to 1500° or 1400° C.[2,3]

The use of basic open-hearth or blast furnace slag as a bond in building hearths and banks of magnesite grain introduces additional iron oxide into the lining of a furnace. The resulting high iron oxide content of a steel furnace bottom has proved a source of considerable difficulty as regards both the life of the lining and the quality of more drastically refined steels, particularly in electric furnace practice. Both of these difficulties arise from the fact that the liquid steel of the furnace bath is continuously striving to attain equilibrium with the iron oxide of the hearth lining. If the concentration of oxygen in the liquid steel is lower than the concentration which would be in equilibrium with the iron oxide in the hearth, then the molten steel dissolves some of the iron oxide of the hearth. This solution of iron oxide from a magnesite furnace lining may take place whether the molten metal bath is high or low in carbon. When the liquid steel bath is high in carbon, as, for example, immediately after the melt down of a charge containing a considerable proportion of pig iron, the bath reacts rapidly with dissolved oxygen and carbon is eliminated from the metal as carbon monoxide. The high carbon content of the metal thus keeps down the concentration of dissolved oxygen and iron oxide tends to be dissolved from the basic furnace lining. On the other hand, if the carbon content of the metal bath has been brought to a low value by addition of ore, the concentration of dissolved oxygen will be relatively high and there will be little or no attack of the iron oxide of the refractory lining. However, if this metal is killed in the furnace by additions of silicon and manganese preparatory to tapping, the dissolved oxygen concentration is at once brought to a very low value. The liquid metal then will rapidly dissolve iron oxide from the magnesite lining.

Under either set of conditions, whether the steel-bath is high or low in carbon, the solution of iron oxide gradually destroys the bond of the lining and in course of time a portion of the lining may become detached from the bottom and rise through the metal. When this happens fresh surfaces of magnesite rich in iron oxide, both on the remaining bottom and on the rising detached portion, come into contact with the liquid metal and the steel is rapidly oxidized. The lining is thus injured and the steel itself, which may have been nearly at the point of finishing under a carefully made slag, may be seriously changed in composition and may again require deoxidation and holding for an additional cleaning period.

It is evident that some bond other than iron oxide in rammed-in magnesite linings would be very desirable.

Unger[4] has described a magnesia lining made of fused magnesium oxide which contained only from 0.2 to 0.5% Fe_2O_3 and was bonded with a material containing no iron. Unger's lining mixture, which has been known as "Furnite" consists of 85 parts of graded sizes of fused magnesia, 8 part of calcined magnesia, and 7 parts of anhydrous pitch. This material was rammed on the furnace hearth in layers 1 to 2 inches thick, heated slowly to coke the pitch and then heated more strongly. Unger stated that the anhydrous pitch furnished only a temporary bond keeping the refractory in place until the temperature became high enough to recrystallize the magnesia.

Scharschu[5] in a patent antedating Unger's description of the "Furnite" lining, had claimed the process of bonding the same general type of refractory mix by burning carbon out of the surface of the refractory, with the simultaneous sublimation of magnesia. The sublimed magnesia crystallized in the pores between the grains of the prefused magnesia and thus acted as the final bond.

DEVELOPMENT OF WATER-GROUND MAGNESIA BOND

Several years ago in the experimental foundry of the National Bureau of Standards it was desired to line an indirect arc, rocking electric furnace of the Detroit type for melting steel. The linings which at that time were available commercially for this furnace were suitable only for non-ferrous melts. A rather pure magnesia lining appeared to be the most suitable for the experimental work in hand but it was not certain what type of bond would serve best for the rammed-in lining and to anchor this lining to the supporting lining of commercial magnesite brick, placed next to the steel furnace shell. Particular attention was also paid to the requirement that any bonding material used should be free from the objectionable features of iron oxide bonds.

Small magnesia crucibles for melting steel had been successfully used for some time in Arsem and in high frequency induction furnaces. These crucibles were bonded with about 15% zirconium silicate, or with 2% magnesium chloride, or the electrically sintered magnesite comprising the main portion of the crucible was bonded with small additions of less heavily calcined magnesia.

* Publication approved by the Director of the Bureau of Standards of the United States Department of Commerce.

† Chief, Section of Thermal Metallurgy, Bureau of Standards.

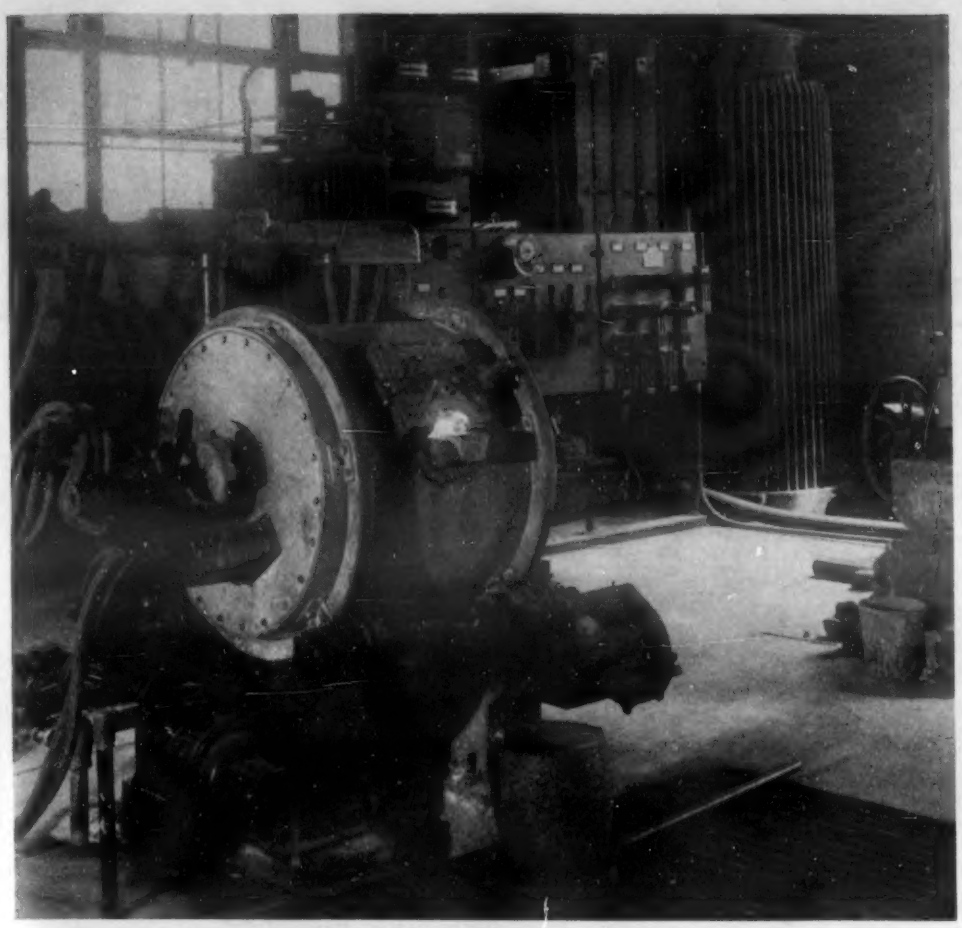
[1] J. S. McDowell. Magnesite Refractories. *Journal American Ceramic Society*, Vol. 6, 1923, page 280.

[2] R. M. Howe. Refractories for Electric Furnaces. *Foundry*, Vol. 48, 1926, pages 911–913.

[3] A. B. Searle. Refractory Materials for Electric Furnaces. *Beama*, Vol. 11, 1922, pages 644–670.

[4] M. Unger. Refractories for Induction Furnaces. *Transactions American Electrochemical Society*, Vol. 50, 1926, page 147.

[5] Charles A. Scharschu. U. S. Patent 1,444,527, Feb. 6, 1923.



Detroit Rocking Electric Furnace in the Bureau of Standards laboratories melting experimental high speed tool steels on a lining of magnesite bonded without iron oxide.

The material for lining this furnace was prepared as follows:

(A) Commercial electrically sintered magnesia, purchased as 16-mesh and finer, was ground in a disk mill to give a product which contained about 50% of material passing an 80-mesh sieve and about 50% between 30 and 80 mesh. This material is designated as "dry ground magnesia."

(B) Equal weights of water and of electrically sintered magnesia, 80-mesh and finer, were ground in a ball mill with a load of flint balls equal to the weight of the dry magnesia. For a 100-pound charge (50 lbs. MgO and 50 lbs. water) this grinding was continued for 16 hours. After completion of the grinding the magnesia "slip" was poured from the mill into a settling vat and allowed to stand for about 17 hours (over night). The magnesia settled somewhat and the supernatant water was decanted. This water amounted to about 6 or 7% of the weight of the ball-mill charge. On the basis that 50% of the weight of the slip as poured from the ball mill (before settling) was MgO, it was possible to calculate the MgO content of the concentrated slip after the 6 or 7% water had been poured off. The final product of this wet grinding is designated as "magnesia slip" and the solid constituent of the slip as "water-ground magnesia."

The amounts of the above materials required for lining the furnace hearth were 240 pounds of dry ground magnesia mixed with 100 pounds of the magnesia slip which contained slightly more than 50% magnesia. This gave a mixture of approximately 80 parts dry magnesia to 20 parts of water-ground magnesia. About 50 pounds of magnesia slip in excess of that required for mixing with the dry ground magnesia were prepared for use in washing the surface of the magnesite bricks before tamping in the mixture of dry-magnesia-slip.

A number of preliminary experiments were made using these magnesia mixes as a cement between small test pieces of commercial magnesite brick.

It was learned from the preliminary tests that commercial magnesite brick could be cemented together rather well with a properly proportioned mixture of water-ground electrically sintered magnesia and of coarse electrically sintered magnesia. Water-ground sintered magnesia had also been used in earlier work, sometimes for bonding material and sometimes as washes for ingot molds. These bonds were of particularly good strength when they were fired at 1600° to 1700° C. in a reducing atmosphere, as in an Arsem furnace. The bond was less satisfactory when the specimens were fired to the same temperatures in a gas furnace.

Further preliminary tests were made in which the roughened surface of a commercial magnesite brick was painted with a coating of water-ground magnesia and then a layer, 1 to $1^1/_2$ inches thick, of bonded 80-mesh electrically sintered magnesia was rammed firmly on the painted surface. Both zirconium silicate and water-ground magnesia were used as bonds in the 80-mesh magnesia in these tests. The water-ground bond appeared to give just as strong a refractory in the rammed layer and also as good adherence to the magnesite brick surface as did the silicate bond. It was decided, therefore, to use the water-ground magnesia bond for an experimental lining in the Detroit furnace and thus have present in the rammed lining no impurity which might lower its refractoriness.

EXPERIMENTAL LINING OF AN INDIRECT ARC FURNACE

The hearth of the furnace in which the experimental lining was built was 16 inches in diameter by about 14 inches long. These dimensions were inside a lining of commercial magnesite brick laid against the walls of the furnace shell.

It should be noted that it is a matter of judgment on the part of the individual lining the furnaces as to whether the 80-20 mixture made up as above is too wet or too dry. Variations in the relative amounts of coarse and fine material in the dry ground magnesia may be the cause of different proportions of water being required to give the correct consistency. Either ground magnesia or water should be added to the approximately 80-20 mix until a handful, if squeezed tightly, holds its shape but does not allow excess moisture to squeeze out. The mix should not be so moist as to become at all muddy when rammed in place on the roughened bricks.

Before building up the lining the inside faces of the magnesite bricks were roughened by chipping. A small section of these roughened faces was then painted with a liberal coat of the magnesia slip and the prepared mixture immediately rammed solidly down on the painted section, building up the full desired thickness of the rammed lining at once. An adjoining section of the roughened brick faces was then painted and the tamped lining continued over this fresh section. It is necessary to line the entire shell without any considerable interruption.

The rammed lining was built up to a thickness of about $1^1/_2$ inches over the cylindrical walls of the furnace and to about $2^1/_2$ to 3 inches where the ends of the furnace join the cylindrical wall.

After the complete lining was tamped in place it was allowed to air dry for several days. It was then dried

out with a gas flame, at first with a rather soft flame and then with a more intense flame. Finally the burner was removed, the furnace arc was struck and the entire lining was heated until temperature readings, taken with an optical pyrometer sighted on the back wall through a small opening in the furnace spout and with the arc turned off, were at least 1800° C. A considerable amount of smoke remained within the furnace for some time after the arc was cut off. Temperatures were read through this smoke and were thus lower than the true temperatures of the magnesia walls.

The lining thus burned appeared to be firmly bonded to the backing brick. It showed a number of "alligator" or "mud" cracks but no appreciable amount of the lining fell off from the walls. In the case of the first lining of this type which was put in a Detroit furnace the alligator or mud cracks in the completely burned lining were partly filled up by making a small amount of a dry mixture of about 1 part alundum, and 2 parts kaolin on the hearth of the furnace, fusing this to a slag under the arc and rocking the furnace. In another procedure for filling alligator cracks the lining, after complete burning in, was sprayed with water glass, dried and then a small melt of iron turnings was made on the hearth and the furnace rocked. This procedure probably slightly glazed the face of the lining but did not fill mud cracks as well as the first procedure.

The lining material, after the final burning, had an apparent density of about 2.3 grams per cubic centimeter while the true density of the burned magnesia of the lining, as obtained by the loss of weight in water of a 25 gram section of the lining, was about 3.2 grams per cubic centimeter. Periclase crystals (MgO) have a density close to 3.6 grams per cubic centimeter. The average coefficient of thermal expansion of this type of bonded magnesia has been reported by Merritt[6] as 13.4×10^{-6} microns per centimeter per degree C. between 25° and 800° C.

[6] G. E. Merritt. The Thermal Expansion of Some Fused Oxides Used as Refractories. *Transactions American Electrochemical Society*, Vol. 50, 1926, page 165.

SERVICE OF THE MAGNESIA LINING

The service required from the small arc furnace lined as described was rather severe. Usually each heat was started with a cold furnace. Heats of ferrous alloys were made of compositions varying all the way from gray cast iron to special high speed tool steels and alloy steels. Many of the melts were superheated.

The first lining installed in this furnace had a life of a very few less than 200 heats of ferrous alloys—about half cast iron and half steels. It finally required replacement not so much from any effect of the iron heats on the magnesia as from the injury suffered in the course of experimental patching tests.

One of the more satisfactory mixtures for patching was found to consist of 2 parts of sintered magnesia, 30-mesh and finer and 1 part each of alundum and kaolin. The mixture was moistened with water, rammed in place, in the cold furnace, air dried and burned in under the arc.

SUMMARY

Furnace linings of electrically sintered magnesia bonded with water-ground magnesia have shown excellent mechanical strength and very satisfactory service in rocking electric furnaces of the indirect arc type melting ferrous metals, often under rather severe conditions as to super-heating and intermittent use.

This type of lining is believed to be free from the objections that have frequently arisen with respect to the disintegration of basic steel furnace linings resulting from the use of iron oxides or basic slags high in iron as bonding materials.

READERS' COMMENTS

To the Editor,
METALS & ALLOYS:

New scientific discoveries are made frequently these days. Occasionally, the achievements relate to metallurgy. One such just came to my attention in a long explanatory letter addressed to me by a company which had previously sent me a circular letter glowingly describing the effectiveness with which "yield point, elastic limit, ultimate strength, elongation and reduction of area" all simultaneously are improved in steel as the result of introducing a newly developed alloy. It was claimed to be equally efficacious in gray iron.

In acknowledging the circular letter I requested information regarding the constituents of the material; remarking that I had yet to see any compound or element which when added to liquid steel, would increase to appreciable degree, each physical property mentioned in the circular.

The reply, which required the use of three and a half pages of single space matter, is such a curiosity that I am prompted to share my enjoyment with your readers. For instance:

"Professor———, who developed this alloy, advises me that our alloy is not, as many alloys are, constituted of just one element. Our alloy is comprised of a number of elements. These elements are so constituted in number and percentages that when the proper proportions of the metallic and non-metallic concentrates are used and fused into an alloy, remarkable results are obtained at a very low cost.

"Professor——— advises me that the following elements are contained in the minerals from which this alloy is made:

"Rutile, Manaccanite, Sphene (wedged crystals), Ligurite, Spinthere or Semeline, Byrl, Lederite, Greenovite (containing Manganese), Aspidelite, Pictite, Guarinite, of dark yellow tabular, and Tischeffkinite, velvet Black, the composition of which has been known to consist of silica, titanic acid, thorium, uranium, iron, manganese, yttrium, cerium, lanthanium, didymium, magnesia, lime, potash, soda, etc.

"The composition can be still greatly increased as many more evidences of their minerals are seen with the disintegrate lens which form a most profound and interesting study. * * * * *

"In preliminary tests which we have made, the reports given us by metallurgists have contained the following statement: 'A perfect deoxidizer and powerful denitrogenizer, also a proficient defiberizer.' * * * * *

"It has been shown that by the introduction of from 1/2 to 1% of our alloy into a measured mass of molten 0.20% carbon steel, as taken directly from the converter, air cooled and subsequently annealed, the elastic limit had increased from 56,000 lbs. per square inch, which was the tensile strength of the natural stock, to 74,000 lbs. per square inch, besides an elongation of from 6.5% in the natural steel to 28.5 with alloy added. * * * * *

"It may be definitely stated that our alloy in greatly decreased proportions than those being used in general practice, may be substituted for both manganese, aluminum and ferro-silicon."

Since METALS & ALLOYS is continuously searching for information concerning new metallurgical developments, I thought you might like to know that an important discovery has been made.

Yours truly,
R. A. BULL, Director,
Electric Steel Founders' Research Group.

Chicago, Ill.
Dec. 3, 1931

New Developments in Unburned Magnesite Brick for Metallurgical Industry*

BY A. E. FITZGERALD

Condensed by M. F. Béhar

With a melting point of 5072° F, magnesium oxide is by far the most refractory of common oxides. It has found large-scale use in the lining of metallurgical furnaces since the latter part of the 19th century when extensive deposits of magnesium carbonate were discovered in southern Austria, displacing much of the calcined dolomite used in basic steel furnaces, which had proved objectionable because its lime content slaked on exposure to atmosphere, preventing its being made into permanent furnace bottoms or brick. The Styrian magnesite's low lime content freed it from this objection.

Ordinary brick-making methods proved inapplicable. Raw magnesite contained approximately 50 percent CO_2. This was removed by calcining to above 2750° F. and the remaining magnesia sintered together to form hard, volume-stable grains of well-crystallized periclase, the so-called "dead-burned" grain magnesite. This calcine was then crushed and ground to pass a 10-mesh screen, moistened with water, molded into brick, dried, and burned again to 2750° F. No bonding agents were added. The second burning operation sintered the magnesite grains together so that brick were strong and suitable for use in metallurgical furnaces, but this second burning being recognized as an economic waste, efforts were made to press the dead-burned magnesite into brick with the addition of chemical binders which would develop a strong brick on drying without the second burning operation. It was found that such brick would sinter and bond well under the heat of the furnaces. There proved, however to be two defects in the unburned brick—(1) the sintering action was accompanied by shrinkage of the brick; (2) sintering action did not extend into the parts of the brickwork which only attained intermediate temperatures, and the bricks in these sections lacked a strong bond.

After extensive research at General Refractories Co. laboratory, three improvements overcame the shrinkage problem: (1) The pressure under which bricks were formed was increased from 1000 lb. to 10,000 lb./in.^{2} greatly reducing amount of void space between magnesite grains. (2) Interfitting of grains was developed to a maximum by proper gradation of sizes. This greatly intensified the effect which the increased forming pressure produced. (3) A colloidal coating for the magnesite particles was prepared, causing them to interfit better under the forming pressure. This third improvement further intensified the benefits of the first and second, and the three combined solved the unburned brick shrinkage problem. This combination also solved the problem of maintaining strength of unburned brick at all temperatures. The colloidal coating on the magnesite particles was so chosen that it developed a strong bond on drying. The fact that the particles were pressed and interfitted so closely increased the bond. As a result, the unburned brick, on drying, were as strong as burned brick, and they maintained this strength at all furnace temperatures.

Descriptions of the special equipment developed to translate laboratory improvements into full-scale production are then given.

Commercially produced unburned brick were tested and found even better than those produced on a semi-commercial scale in the laboratory.

Commercial unburned brick proved also superior to commercial burned brick in various comparison tests.

(1) Shrinkage—Kiln tests, 4 campaigns of 11 days each. Unburned brick shrank only 1.02 percent and burned brick 1.38 percent.

(2) Cold crushing strength—Static loads. Average determination for burned brick gave crushing strength of 7094 lb./in.^{2} for unburned brick 8127 lb./in.^{2}

(3) Rattler test similar to that for paving brick—Burned brick lost 39.2 percent of their weight, unburned brick 33.44 percent.

(4) High temperature bonding strength and refractoriness of bonding agents—High temperature furnaces similar to standard German load testing furnaces. For the burned brick the first deformation occurred at 2725° F., and for the unburned at 2860° F. The burned brick sheared at 2763° F.; the unburned at 2940° F.

(5) Resistance to spalling—Representative lots of 9-in. straight brick were subjected to an air spalling test from 1000° C. They were heated for one hour on their 4-1/2 by 2-1/2-in. face in the doorway of a furnace maintained at 1000° C., the heated brick were removed and cooled in the air for 30 min. and then replaced in the hot furnaces. This heating and cooling was repeated for 20 cycles. The burned brick lost on an average 48.9 percent of their original weight in 20 cycles, while the unburned brick suffered no loss in the same 20 cycles.

(6) Permeability to gases under pressure (infiltration test)—A comparative test was made by noting the time required to pass 1000 cc. of air through a 2-1/2-in. thickness of the brick. For the burned brick 2-1/2 sec. were sufficient, whereas for the unburned brick, 150 sec. were necessary.

That unburned brick are more practical is evident from the following: Lower manufacturing cost and lower selling price; shorter manufacturing time; quicker deliveries; better workmanship; and the fact that unburned brick, pressed exactly to size, are free from warping and kiln-marking and can be laid with better joints.

Results in service. Author asserts that three years' observations on a variety of installations indicate that unburned magnesite will generally replace burned magnesite and chrome brick, and, further, replace to a considerable extent fire clay and silica brick.

Such replacement is not only possible but economically desirable. The field for high-quality unburned magnesite brick seems virtually untouched. Many of the better-known refractory outlets in the metallurgical industries, however, have been thoroughly investigated. Among these are the following:

Basic open hearth. Unburned brick possess all advantages of the burned magnesite for sidewall service, are more economical and due to their greater resistance to spalling can be used more extensively also where the brick are not covered by grain magnesite or dolomite, as front walls and back walls, particularly in tilting furnaces. Other applications are the downtakes of the regenerative checkers and endwalls of sharp-working furnaces.

Electric furnaces. In one instance, unburned magnesite doubled the life of tap holes.

Other successful replacement applications are—mixer linings in open-hearth plants using molten pig iron: lower sidewalls and bottoms of soaking pit chambers; bottoms and lower sidewalls of furnaces heating bars or billets for the manufacture of steel sheets, etc.; copper reverbatory smelting furnaces; copper refining furnaces; silver refining furnaces.

* Original in *Mining & Metallurgy*, Vol. 12, Dec. 1931, pages 527-432.

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The Duriron Company has opened a sales office in Buffalo under the management of Guy A. Baker, who comes from the General Office at Dayton.

The new office address will be Room 420, Jackson Building, 220 Delaware Avenue, Buffalo, New York.

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Erle G. Hill, graduate of the University of California, has been appointed to the incumbency of the industrial fellowship established by the Lukens Steel Co. at Mellon Institute. He was previously associate professor of metallurgy in the School of Mines of the University of Pittsburgh.

Everdur Metal—A High Strength, Corrosion Resistant Engineering Material

BY C. B. JACOBS, JR.

FOR many years the efforts of metallurgists have been directed to finding some element or elements which, when added to copper, would alloy with it and give to copper a strength approaching that of steel, and at the same time retain or augment the non-rusting and corrosion resistant properties of copper. The addition of silicon and manganese to copper, when their proportions are properly adjusted, produces a copper-rich alloy of the solid solution type which attains the desired objective to a remarkable degree. It has long been known that the addition of small amounts of silicon relieves copper of any unsoundness by eliminating oxygen and driving off hydrogen occluded during the melting. Everdur Metal is the first commercial application of copper containing substantial proportions of silicon and marks a decided advance in the metallurgy of copper alloys.

In addition to non-rusting properties and high strength, Everdur possesses many qualities not usually found in metals of this character. It is resistant to corrosive gases and saline fogs and is particularly suited to engineering purposes. Everdur has excellent machining and working characteristics and can be fabricated into a variety of forms and shapes. It is also welded readily by both gas and electric methods.

The proportions of its constituent parts are so carefully adjusted that when remelted and cast, sound homogeneous castings of high strength, toughness and workability are produced.

Everdur Metal was developed during the World War by the duPont Company to meet corrosive conditions existing in some of its own operations which were not met satisfactorily by alloys commercially available. Several years later the patent rights were purchased by The American Brass Company, which is now the exclusive manufacturer of the metal.

Everdur is in reality copper, hardened and strengthened by the addition of silicon and manganese. For the purpose of making sand castings the metal contains 94.3% copper, 4.5% silicon and 1.2% manganese. For wrought forms, Everdur contains 96% copper, 3% silicon and 1% manganese. Wrought Everdur is hardened by rolling and drawing with a marked increase in tensile strength. Its strength and fatigue limit are comparable to those of steel.

One of the most important features of Everdur Metal is the wide range of forms and means by which it can be worked and fabricated. Sound castings can be obtained by using the regular equipment of brass and bronze foundries. It can be rolled, drawn, spun and headed by both hot and cold methods. It makes excellent hot forgings and die pressed parts. It gives economic production of machined parts. Its weldability has made its use possible in many fields of engineering. Sound welds, developing practically the same strength as the metal itself, can be made by any of the usual welding methods.

Everdur is produced by The American Brass Company in the form of sheets, strips, plates, wire, rods, shafts, tubes, shells, pipes, hot pressed parts, rivets and casting ingots.

With the strength and workability of steel, immunity to rust and high resistance to a wide variety of corroding agents, Everdur is used for a wide diversity of applications and has been applied to many engineering and structural problems.

The employment of Everdur in the field of hot water storage tanks and pressure vessels has developed rapidly. Five nationally distributed automatic domestic hot water heaters are equipped with Everdur tank units and specially designed Everdur tanks and pressure vessels are in service in sizes ranging up to 20,000 gallons in capacity. These are installed as hot water storage tanks in laundries, textile plants, apartment houses, hotels, office buildings, etc., and as operating and storage units in chemical processes. They have been constructed by a variety of methods including riveting, metal and carbon arc welding, oxy-acetylene welding and resistance seam welding.

Among the many diversified applications of Everdur Metal are bolts, nuts and screws for transmission line hardware and fastening for boats and yachts; louvers, ducts, fans, drain pipes and grills for venting acid fumes and solutions from battery and plating rooms; tie rods, bolts and channels for pickling tanks; equipment for reservoirs and sewage disposal plants; sheet metal and cast parts for smoke pipes and smoke and soot washers; oil and fuel lines and gasoline tanks for airplanes; deck hardware and parts for boats; well screens made from tube, sheet metal and wire; stack flashings; spandrels; switch boxes and other items for railway signal equipment; skylight frames; cast circuit breaker domes; shovels for handling acid sludge and other corrosive and explosive materials; grave vaults; pump shafting; pumps, valves and equipment for handling acids and other corrosive chemicals; manhole steps; window-cleaners' bolts; dynamite mixing bowls; varnish kettles; grain conveyers; "save-all" pans for paper mills; dye kettles; heat exchanger equipment and numerous other uses where high strength and corrosion resistance is essential.

Notice

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